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OZONE BEHAVIOR IN THE COMBINED BALTIMORE-WASHINGTON, DC PLUME

by

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An extensive air quality monitoring program was carried out in the Washington, DC - Baltimore region during the July 14 - August 15 period in 1980. This field study included data collection at numerous ground stations as well as the use of two aircraft sampling platforms. Measurements included ozone, oxides of nitrogen, individual hydrocarbons (C_2-C_{10}), condensation nuclei and visual distance plus numerous meteorological parameters. Specific areas of interest in this study included the acquisition of air quality data for (1) developing and testing a regional air quality simulation model and (2) gaining a better understanding of oxidant production and transport in plumes emanating from Washington, DC and Baltimore. The purpose of this report is to describe oxidant behavior downwind of these two cities in cases where plume interaction was observed. We have selected seven days during the 1980 study period when southwesterly winds carried the Washington, DC plume into the region occupied by the Baltimore plume. A case study analysis was performed for each of these days and general conclusions have been presented regarding oxidant patterns in the regions where plume interactions occurred.

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ABSTRACT

An extensive air quality monitoring program was carried out in the Washington, DC - Baltimore region during the July 14 - August 15 period in 1980. This field study included data collection at numerous ground stations as well as the use of two aircraft sampling platforms. Measurements included ozone, oxides of nitrogen, individual hydrocarbons (C_2-C_{10}), condensation nuclei and visual distance plus numerous meteorological parameters. Specific areas of interest in this study included the acquisition of air quality data for 1) developing and testing a regional air quality simulation model and 2) gaining a better understanding of oxidant production and transport in plumes emanating from Washington, DC and Baltimore. The purpose of this manuscript is to describe oxidant behavior downwind of these two cities in cases where plume interaction was observed. We have selected seven days during the 1980 study period when southwesterly winds carried the Washington, DC plume into the region occupied by the Baltimore plume. A case study analysis was performed for each of these days and general conclusions have been presented regarding oxidant patterns in the regions where plume interactions occurred.

CONTENTS

Abstract iii

Figures. vi

Tables vii

Acknowledgments. viii

1. Introduction 1

2. Summary and Conclusions. 3

3. Experimental 7

4. Results and Discussion 8
   Oxidant Precursor Emissions. 8
   Plume Interaction. 8
   Plume Dimensions 27

References 34

Appendices

A. Data Summary and Analysis for July 19, 1980. 35
B. Data Summary and Analysis for July 21, 1980. 50
C. Data Summary and Analysis for July 25, 1980. 58
D. Data Summary and Analysis for August 2, 1985 68
E. Data Summary and Analysis for August 3, 1985 75
F. Data Summary and Analysis for August 5, 1985 85
G. Data Summary and Analysis for August 14, 1980. 94

FIGURES

Number		Page
1	Surface (6-9 AM) nonmethane hydrocarbon distribution frequencies in Baltimore during the 1980 study period	10
2	Surface (6-9 AM) nonmethane hydrocarbon distribution frequencies in Washington, DC during the 1980 study period. .	10
3	Baltimore-Washington, DC plume interaction scenarios	12
4	Map showing the oxidant plume boundaries, tetroon trajectory and location of crossplume aircraft traverses on August 14, 1980 by WSU aircraft	14
5	Crossplume ozone and NO_x profiles recorded 20 km downwind of Baltimore at 1500 ft on August 14, 1980 by WSU aircraft . . .	15
6	Crossplume ozone profile recorded 190 km downwind of Baltimore at 3000 ft. on August 14, 1980 by WSU aircraft.	17
7	Map showing ozone plume characteristics downwind of Baltimore and Washington, DC on July 19, 1980	20
8	Map showing ozone plume characteristics downwind of Baltimore and Washington, DC on August 3, 1980.	24
9	Cross-sectional ozone profile recorded in plume interaction region (traverse DE Figure 8) with hypothetical individual ozone plumes represented by dashed lines.	26
10	Crossplume ozone profile recorded 60 km downwind of Baltimore and ~115 km downwind of Washington, DC at 3000 ft. on July 25, 1980. Dashed lines represent individual plumes .	28
11	Crossplume ozone profile recorded 60 km downwind of Baltimore at 1500 ft. on August 5, 1980 by WSU aircraft	30
12	Crossplume ozone profile recorded 60 km downwind of Baltimore at 1000 ft. on July 19, 1980 by WSU aircraft	31
13	Crossplume ozone profile recorded 60 km downwind of Baltimore at 2500 ft. on July 19, 1980 by WSU aircraft	33

TABLES

Number		Page
1	Summary of 6-9 AM Hydrocarbon Data During 1980 Study Period	9
2	Average Upper Level (1000-3500 ft) Wind Speed and Direction Data Recorded on JULY 19, 1980	21

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SECTION 1

INTRODUCTION

During July and August of 1980, EPA sponsored a large air quality monitoring program in the northeastern United States. Federal, state and private research organizations worked together to acquire a comprehensive data base that includes numerous meteorological parameters as well as gaseous pollutant information. Primary objectives of the study were to establish a data base that could be used for development and testing of a regional scale photochemical air quality simulation model and to provide states in the northeastern United States with data useful for State Implementation Plan revisions. A complete description of the experimental program, quality assurance procedures and data archiving has been reported elsewhere (1).

Field studies in the vicinity of many US cities have documented the production and transport of ozone in urban plumes. There is little doubt that urban areas are the major contributors of precursors that lead to oxidant production. Elevated ozone levels have been recorded in urban plumes emanating from cities of various size. For example, Spicer et al. showed that oxidants produced in the Springfield, IL (pop.~100,000) plume could be tracked for distances of 70 km downwind (2). Studies in Houston, Boston and many other large cities have established oxidant transport distances in excess of 100 km (3).

Since one of the primary objectives of the 1980 Northeast field study was to obtain a data base for photochemical modeling purposes, it was essential that the physical and chemical characteristics of urban plumes in the region be well understood. Consequently, a great deal of effort went into characterizing the plumes from Baltimore, Washington, DC, New York City and Boston. Four fixed wing aircrafts and a helicopter were employed to monitor the chemical composition and dispersion behavior of these plumes. In Baltimore, Lagranian plume tracking experiments were performed with the aid of tetroons. On one occasion, a tetroon released near Baltimore provided a means of tracing the air parcel as far as New York City. Many Eulerian type studies were conducted in which aircraft flight paths crisscrossed the Baltimore and Washington, DC plumes at fixed distances upwind and downwind of the cities.

Needless to say, a great deal of data was collected which can be utilized to provide an improved understanding of photochemical oxidant production in urban plumes. The close proximity of the Baltimore and Washington, DC urban centers provided an unique opportunity to examine the effects created when the plume from one large city impinges on that of another. The purpose of this report is to describe plume behavior in cases when the Baltimore and Washington plumes overlap. We have selected seven days during the 1980 study period when southwesterly winds carried the Washington, DC plume into the region occupied by the Baltimore plume. A thorough case study analysis was performed for each of these days, the results of which are included in this report (Appendices A - G). In addition to this case by case analysis, we have presented general conclusions regarding oxidant behavior in regions where plume interactions occur.

SECTION 2

SUMMARY AND CONCLUSIONS

This study has provided information regarding oxidant production and transport in the Baltimore-Washington, DC corridor. An extensive air quality data base obtained from ground level and aerial monitoring platforms was used to establish the vertical and horizontal dimensions of oxidant plumes downwind of these two cities. The primary objective of the analysis contained herein, has been to examine interaction characteristics of the plumes emanating from Washington, DC and Baltimore. Seven days of aircraft sampling were performed during the July 14-August 15, 1980 study period, when winds out of the southwest transported the two urban plumes into the region northeast of Baltimore. A case study analysis was performed for each of these seven days, the results of which allow the following general conclusions to be made concerning oxidant production and transport in the region downwind of Baltimore and Washington, DC.

1) Ambient non-methane hydrocarbon concentrations measured during the 0600-0900 period at ground level urban sites in Baltimore and Washington, DC were very similar in magnitude. The mean NMHC concentrations were 659 and 671 ppbC for Baltimore and Washington, DC, respectively. The NMHC concentration frequency distributions were also very comparable, with the majority of readings falling in the 450-750 ppbC range. The distribution of individual hydrocarbon species by class corresponded to about 60% paraffins, 30% aromatics

and 10% olefins in each city. Assuming sampling sites are representatively placed, these results imply that hydrocarbon emissions are nearly the same in Baltimore and Washington, DC.

2) The mean hydrocarbon/NO_x ratios are not significantly different for the two cities. The Baltimore downtown site exhibited a ratio of 7.0±2.9 while the corresponding mean ratio at the ground level Washington, DC station was 9.5±7.2 (4). The Washington, DC ratio appears to be more variable than the Baltimore ratio.

3) Due to the close proximity of the two cities, meteorological factors that influence oxidant production are normally the same. Since oxidant precursor levels are similar, ozone production in the two plumes would be expected to be nearly the same. Aircraft measurements verify this assumption.

4) Southwesterly winds in the Washington-Baltimore region can lead to direct overlap of the two urban plumes or to varying degrees of partial overlap. In the one case of direct overlap recorded during the 1980 study period, a single oxidant plume was observed downwind of the two cities. Lagrangian measurements aided by the presence of a tetroon traveling at altitudes between 2300 and 3600 ft showed no evidence of ozone production in the air parcel departing Baltimore at 11:00 AM. Ozone concentrations were about 70 ppb within the air parcel as well as to the north and south of the plume. After two hours travel time, in-plume ozone levels were elevated by 40 ppb compared to ozone concentrations outside of the plume boundaries. At 5:00 PM, this same air parcel, which at that time was located 200 km downwind of Baltimore, exhibited peak ozone concentrations of 170 ppb.

Thus, ozone levels in the plume increased from 70 ppb on the outskirts of Baltimore to 170 ppb six hours later at a distance of 200 km downwind of Baltimore. Since oxidant precursor concentrations and atmospheric dispersion conditions on this day were typical of those encountered during the study period, it seems reasonable to assume that ozone concentrations will increase by approximately 100 ppb in an air parcel that passes directly over Washington, DC and Baltimore during the morning hours.

In situations where partial overlap of the urban plumes occurred, highest ozone levels were observed in the region of maximum plume overlap. Because of the geographic location of the two cities, the northern portion of the combined plume contained the region of greatest overlap. Consequently, a crossplume ozone gradient usually existed with highest concentrations in the northern portion of the plume and lower levels to the south. When westsouthwesterly wind flow created a side-by-side overlap of the individual plumes downwind of Washington and Baltimore, a bimodal crossplume ozone profile was observed. Ozone concentrations in the interaction region between the two plume centerlines were commensurate with an additive contribution from each of the individual plumes.

5) A combined Washington, DC - Baltimore plume with enhanced ozone concentration was documented on seven days during the 1980 field study program. On these days, inplume ozone concentrations ranging from 120 to 220 ppb were measured in the region between Baltimore and Philadelphia. Background ozone levels to the north and south of the plume generally ranged between 90-110 ppb during the afternoon hours.

Elevated ozone levels in the Washington-Baltimore plume were observed as far as 200 km downwind of Baltimore. In the region 60-80 km downwind of Baltimore, crossplume ozone profiles at 1500 ft often differed from those recorded at higher altitudes. The low altitude profiles exhibited relatively high ozone concentrations over Chesapeake Bay and along its northern shoreline. The enhanced ozone concentrations are probably the result of limited precursor dilution (shallow mixing layer) and minimal ozone loses due to scavenging over the water.

SECTION 3

EXPERIMENTAL

All data utilized in this Washington, DC-Baltimore plume interaction analysis were obtained from the 1980 Northeast Regional Oxidant Studies (NEROS) and Northeast Corridor Regional Modeling Project (NECRMP) data bases. The U.S. Environmental Protection Agency has compiled air quality and meteorological data supplied by participants in these two programs on magnetic tape. Quality assurance reports which describe the data collection methods and document analytical procedures are available from EPA.

SECTION 4

RESULTS AND DISCUSSION

Oxidant Precursor Emissions

Based on ground level data collected during the study period, there is very little difference in ambient hydrocarbon and NO_x levels measured during the 0600-0900 EDT period in Baltimore and Washington, DC. Table 1 provides a summary of the hydrocarbon data. The total nonmethane hydrocarbon concentration was obtained by summing the individual species at two sites in Baltimore and three sampling locations in the Washington, DC area. It is obvious on examination of Table 1 that mean nonmethane hydrocarbon totals for the two cities are essentially identical as is the distribution of individual species amongst the three hydrocarbon classes. The hydrocarbon concentration frequency distributions were very similar for the two cities as well. Figure 1 and 2 show bar graphs of hydrocarbon distributions in Baltimore and Washington, DC, respectively.

Mean NO_x concentrations recorded at the downtown sites in Baltimore (Read Street) and Washington, DC (W. End Library) were 95 ppb and 94 ppb (4). Richter has calculated hydrocarbon/NO_x ratios for the two downtown sites by averaging all of the individual sums of hydrocarbon species/NO_x ratios recorded at those sites (4). The Baltimore site exhibited a mean ratio of 7.0±2.9 while the Washington, DC ratio of 9.5±7.2 was a little higher and more variable. These ratios fall in the 6-12 range normally reported for large urban centers in the U.S. A median value of 9.5 has been determined

TABLE 1. SUMMARY OF 6-9 AM HYDROCARBON DATA DURING 1980 STUDY PERIOD

	Baltimore	Wash. DC
No. of Samples	159	118
Mean TNMHC (ppbC)	659	671
Minimum value (ppbC)	51	147
Maximum value (ppbC)	2798	2953
Mean % Paraffins	58	59
Mean % Aromatics	29	31
Mean % Olefins	10	6

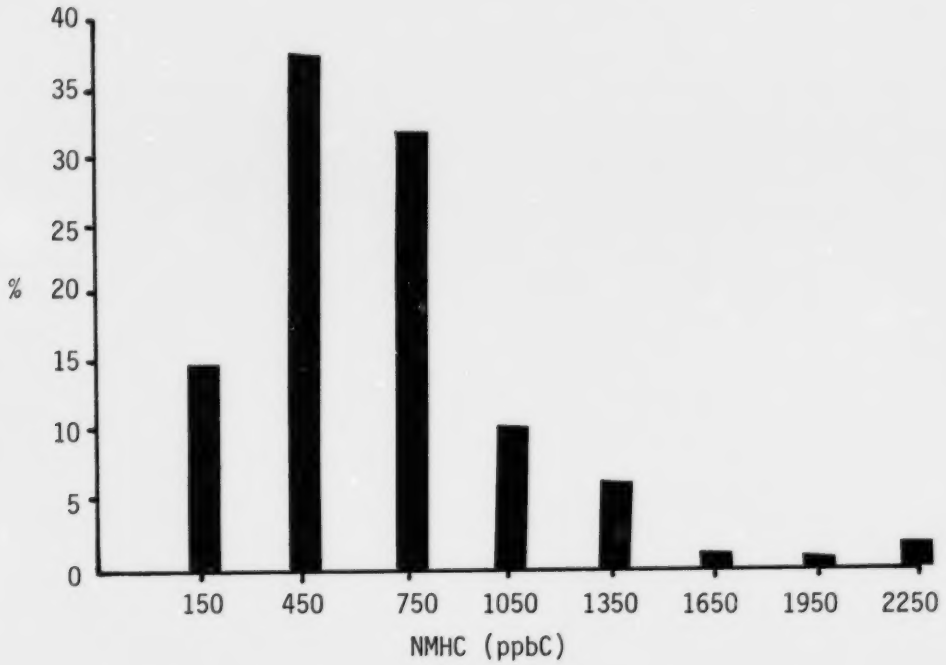


Figure 1. Surface (6-9 AM) Nonmethane hydrocarbon distribution frequencies in Baltimore during the 1980 study period.

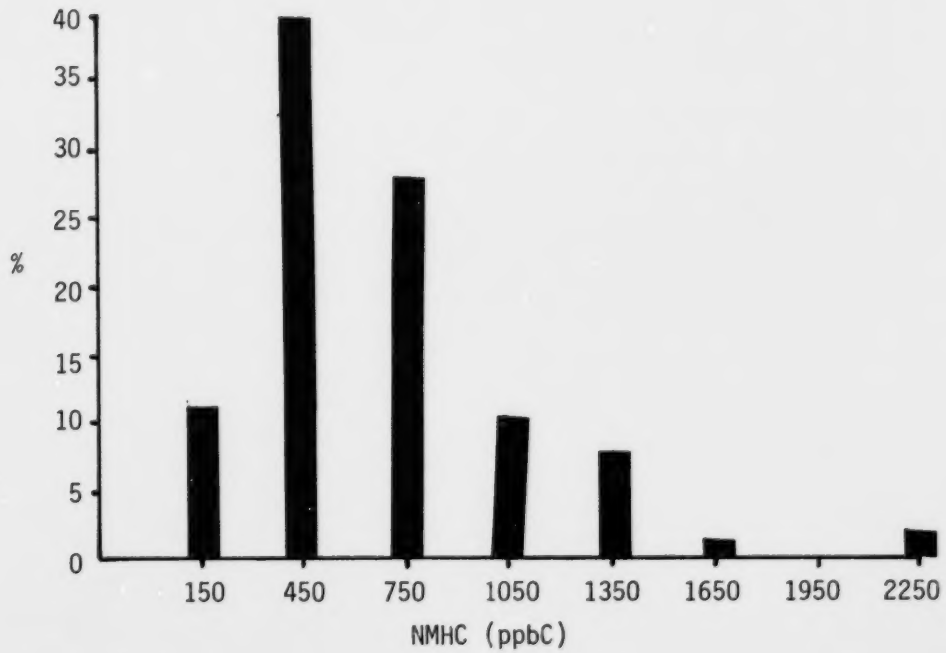


Figure 2. Surface (6-9 AM) Nonmethane hydrocarbon distribution frequencies in Washington, DC during the 1980 study period.

from hydrocarbon and NO_x data obtained in 14 cities (5).

Plume Interaction

Based on data collected during the field program, plumes emanating from Washington, DC and Baltimore can be examined in terms of two different interaction scenarios. On August 14, the Washington plume passed directly over Baltimore resulting in a single plume downwind of the two cities. On several other occasions, winds with a more westerly component created a partial overlap situation in which pollutants emitted in the northern section of Washington, DC passed over Baltimore. This created a bimodal plume with a combined Baltimore and Washington contribution to the north and a Washington-only contribution to the south. Figure 3 illustrates the two scenarios.

DIRECT OVERLAP

Southwesterly winds carried Washington, DC emissions over Baltimore during the morning hours on August 14. An aircraft traverse perpendicular to the wind direction and between the two cities showed a Washington, DC plume approximately 30 km in width impacting directly on Baltimore. A vertical aircraft sounding conducted at 10:30 AM in the Washington plume indicated a mixing depth of about 2000 ft. Since surface winds in the morning hours averaged about 20 km/hr, ozone precursors emitted in the Washington urban area between 0700 and 0800 passed over Baltimore about 1000. A tetroon was released into this air parcel 20 km downwind of Baltimore at 1100. During the afternoon hours the tetroon traveled in a northeasterly direction at altitudes varying from 2300 to 3600 ft. at an average speed of 36 km/hr. The tetroon was tracked with ground based radar and through aircraft contact at points approximately 20, 70 and 190 km downwind of Baltimore.

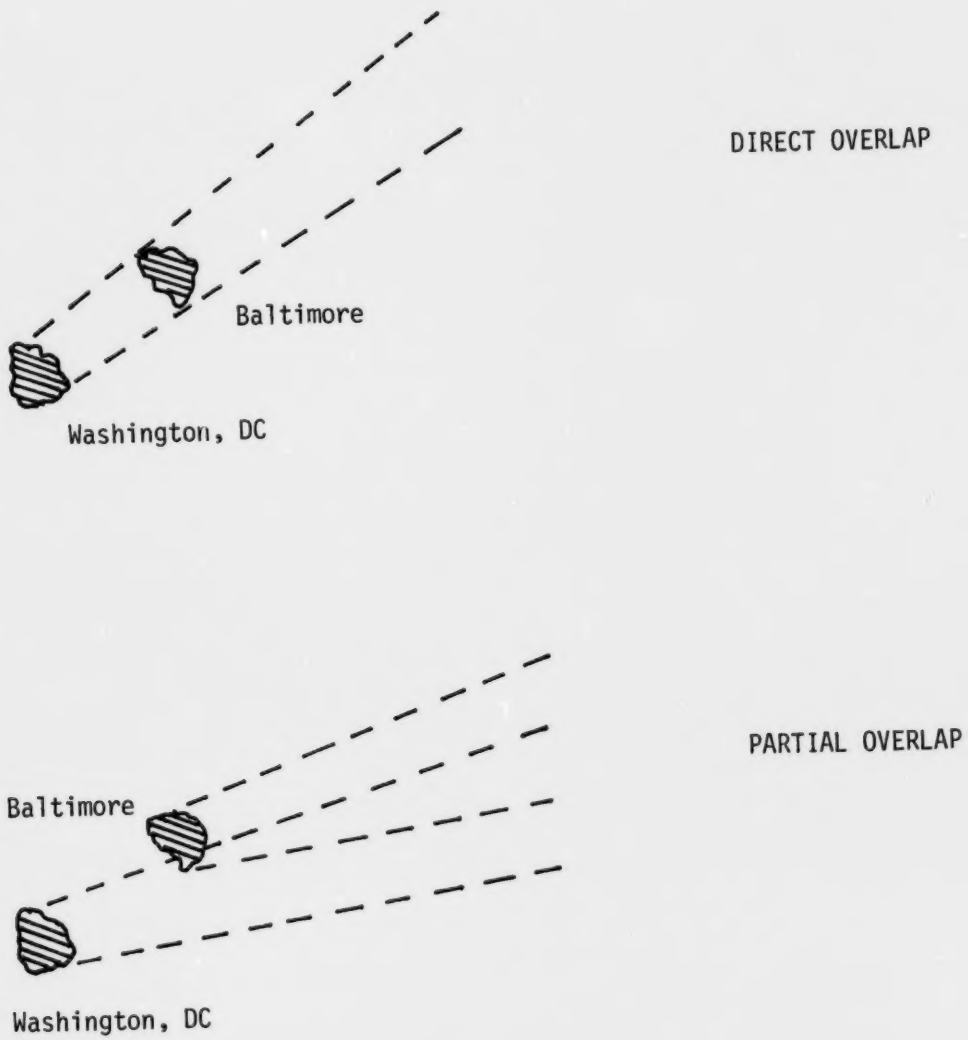


Figure 3. Baltimore - Washington, DC plume interaction scenarios.

Figure 4 shows the tetroon trajectory, the location of aircraft sampling traverses and the approximate boundaries of the oxidant plume on August 14. Crossplume aircraft traverses were accomplished in the vicinity of the tetroon at about 1100 (20 km downwind), 1300 (70 km) and 1700 (190 km).

Assuming that the tetroon accurately represented the temporal and spatial trajectory of the "tagged" air parcel, it is possible to examine the chemical and physical changes that occurred as the air mass traveled downwind. As indicated previously, the "tagged" air mass passed over Washington, DC during the 0700-0800 period and then picked up additional emissions in the Baltimore urban area between 1000-1100. Ambient nonmethane hydrocarbon concentrations at the two Washington, DC surface sites averaged 730 ppbC during the 0600-0900 period on August 14. This is slightly higher than the mean value of 671 ppbC determined for the entire study period. An aircraft sample collected 20 km downwind of Baltimore at 1500 ft showed a nonmethane hydrocarbon concentration of 162 ppbC and a corresponding NO_x level of about 25 ppb. This represents a hydrocarbon/NO_x ratio of approximately 6.5 in the "tagged" air parcel departing Baltimore.

Figure 5 shows the ozone profile recorded at 1500 ft along the traverse 20 km downwind of the Baltimore city center. Background ozone levels outside of the plume were about 80 ppb at 1500 ft. Ozone depletion is evident within the plume with concentrations reduced to the 60 ppb range at three points along the traverse. As expected, the section of the plume with reduced ozone levels also exhibited enhanced NO_x concentrations. Based on the ozone and NO_x profiles, a plume width of about 35 km was observed at the downwind distance of 20 km. Crossplume traverses flown at 3000 and 4500 ft along the same track were above the pollutant plume. At both

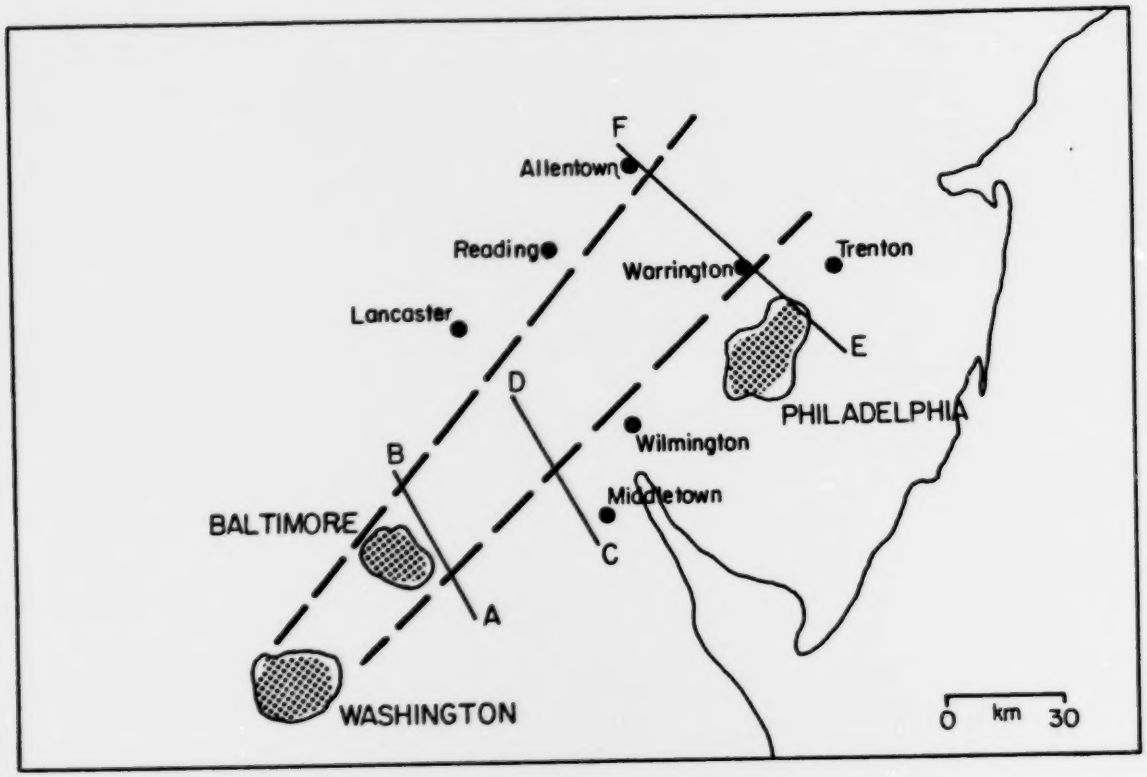


Figure 4. Map showing the oxidant plume boundaries, tetroon trajectory and location of crossplume aircraft traverses on August 14, 1980

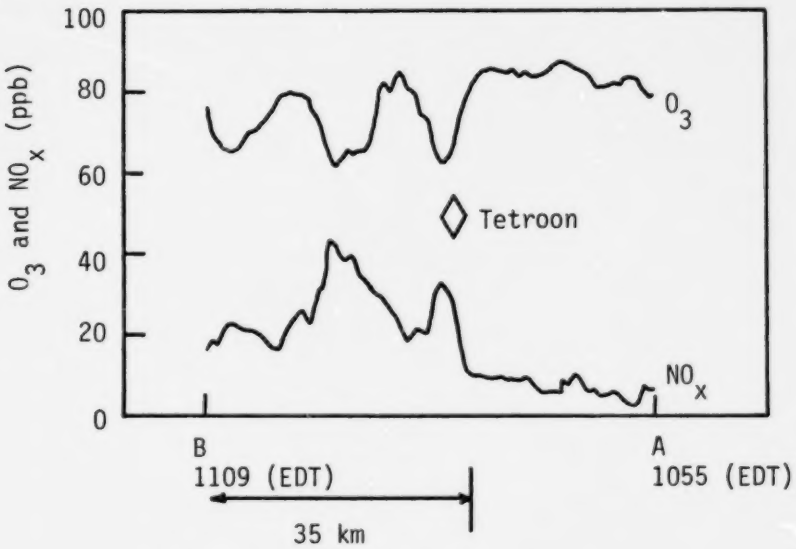


Figure 5. Crossplume ozone and NO_x profiles recorded 20 km downwind of Baltimore at 1500 ft on August 14, 1980 by WSU aircraft

altitudes, stable ozone readings in the 65-75 ppb range were observed which implies that surface emissions were not mixing to those altitudes. A non-methane hydrocarbon concentration of 39 ppbC was recorded in a sample collected above the plume at 3000 ft while oxides of nitrogen levels were 5 ppb or less along the entire traverses at 3000 and 4500 ft. Ground level measurements in the plume 20 km downwind of Baltimore during the 1100 - 1130 period showed ozone levels in the 85-95 ppb range, NO_x concentrations of about 15 ppb and a nonmethane hydrocarbon concentration of 150 ppbC. Thus, the plume departing Baltimore during the late morning hours on August 14 can be characterized as follows: 1) plume width of 35 km at 1500 ft; 2) vertical plume depth less than 3000 ft; 3) nonmethane hydrocarbon concentrations in the 150-160 ppbC range; 4) NO_x concentrations in the 15-40 ppb range, and 5) no ozone build-up in the plume as it left the Baltimore urban area at 1100.

Two hours later at about 1300 the air mass was monitored at a distance of 70 km from Baltimore. In-plume ozone concentrations at 3000 ft were about 40 ppb higher than levels outside of the plume. Thus, vertical mixing had increased to a level greater than 3000 ft. However, a 4500 ft aircraft traverse along the 70 km track showed no evidence of an ozone plume so the mixing level had not reached that altitude by 1300. The width of the plume at 3000 ft was approximately 40 km which indicates that very little horizontal expansion had occurred during the 1100 to 1300 period.

The combined Washington, DC - Baltimore plume was examined for a third time about 1700. The tetroon was located north of Philadelphia at a distance of 190 km from Baltimore. Figure 6 shows the ozone profile recorded along the crossplume traverse at 3000 ft. An ozone bulge which extended from just south of Allentown to Warington, PA is clearly evident. Peak ozone concen-

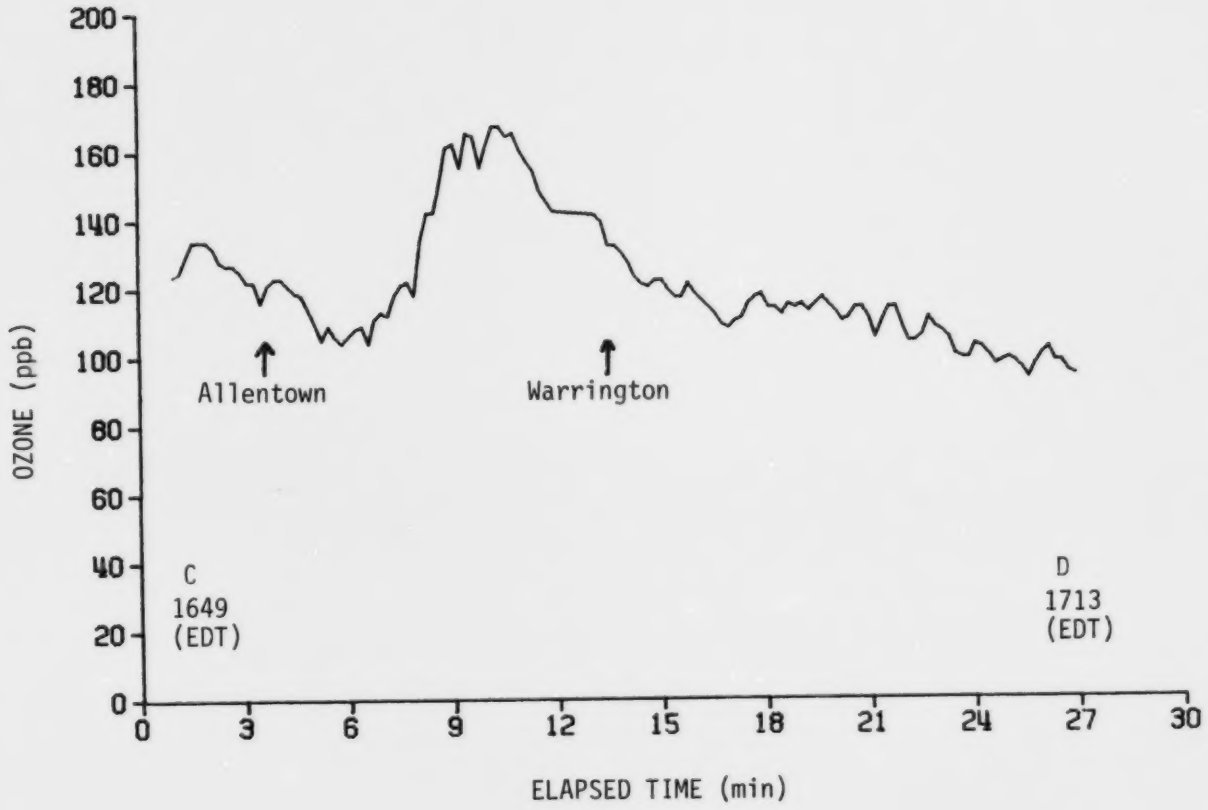


Figure 6. Crossplume ozone profile recorded 190 km downwind of Baltimore at 3000 ft. on August 14, 1980 by WSU aircraft.

trations in the plume approached 170 ppb compared to about 110 ppb outside the plume. In this case, it is difficult to assign a definite background concentration outside of the Baltimore-Washington air mass due to the proximity of urban and industrialized regions both to the north and south of the plume. The plume associated with Baltimore and Washington was approximately 50 km wide at this distance and extended vertically to an altitude of more than 4500 ft. The shape of the ozone profile recorded along the 190 km track at 4500 ft was nearly identical to that shown for 3000 ft in Figure 6. However, peak inplume ozone levels were about 150 ppb as compared to the 170 ppb observed at 3000 ft. At 1500 ft, peak ozone concentrations were also on the order of 150 ppb.

It is impossible to define the individual contribution from Baltimore and Washington, DC to ozone levels produced downwind on August 14. However, the physical and chemical changes in the air mass that departed Washington about 0800 and passed over Baltimore two hours later have been defined. The plume expanded horizontally from a width of 35 km to 50 km after traveling 190 km downwind. Vertical plume dimensions increased from less than 3000 ft at 1100 to greater than 4500 ft by afternoon (1700). Ozone levels in the plume increased from a low of 70 ppb on the outskirts of Baltimore to a maximum of about 170 ppb six hours later at a distance of 190 km from Baltimore. Since oxidant precursor concentrations and atmospheric dispersion conditions on August 14 were typical of those encountered during the study period (See Appendix G), it seems reasonable to assume that ozone concentrations typically increase by 100 ppb in an air parcel that passes over Washington, DC and Baltimore during the morning hours.

PARTIAL OVERLAP

Data collected during aircraft sampling missions on July 19 provide a good basis for examining a partial overlap of the plumes from Baltimore and Washington, DC. Figure 7a shows a map of the study area on July 19. The heavy dashed lines that begin at Washington and extend to the northeast mark the approximate boundaries of the observed ozone plume. The solid lines that transect the oxidant plume show the location of aircraft traverses. It is obvious from wind flow patterns and the geographical location of the two cities that air parcels in the northern portion of the ozone plume had passed over both Washington, DC and Baltimore while the air sampled near the southern edge of the plume was not influenced by pollutants associated with Baltimore. The stippled area in Figure 7a represents the likely region of Washington and Baltimore plume overlap. The area to the south of this overlap region is occupied by pollutants associated with Washington, DC.

Ample sunlight and warm temperatures on July 19 provided good conditions for ozone formation (See Appendix A). Winds in the 1000-3500 ft layer were from the southwest quadrant throughout the daylight period. Table 2 shows average upper level wind speed and direction information obtained at three different stations in the Baltimore-Washington area. Between the hours of 0900 and 1500, the average wind direction was 234° which corresponds to a line connecting central Washington, DC with Wilmington, DE. Wind speeds varied between 10 and 24 km/hr with the average being 19 km/hr during the 0900 - 1500 time period. The mixing height began to increase about 10 AM following breakup of a low level surface inversion. Mixing increased to 3000 ft by 1300 and reached a maximum of about 5000 ft during the mid afternoon hours (See Appendix A).

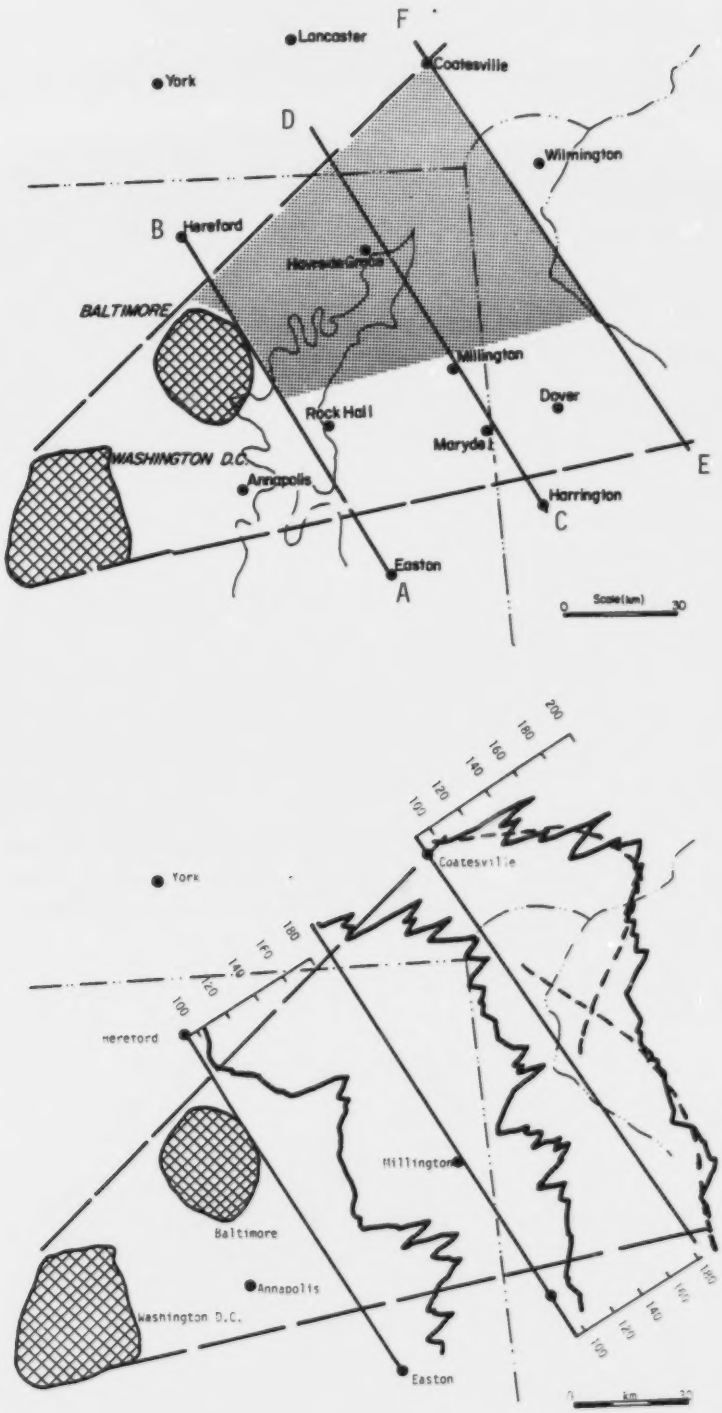


Figure 7. Map showing ozone plume characteristics downwind of Baltimore and Washington, DC on July 19, 1980.

TABLE 2. AVERAGE UPPER LEVEL (1000-3500 ft) WIND SPEED AND DIRECTION DATA RECORDED ON JULY 19, 1980

Time (EDT)	WD (deg)	WS (km/hr)	Station
0900	231	22	Manassas
0900	236	21	Bel Air
0900	224	20	BNL Van (Baltimore)
1000	233	22	BNL Van
1100	-	24	BNL Van
1300	238	24	BNL Van
1400	239	13	Bel Air
1400	225	15	BNL Van
1500	242	10	Bel Air
Ave:	234	19	

Even though July 19 was a Saturday, oxidant precursor levels were quite high in the Baltimore area during the 0600-0900 period. The average nonmethane hydrocarbon concentration recorded at Baltimore stations was 1170 ppbC which is nearly double the mean value of 659 ppbC determined for the entire study period. A surface sample collected 20 km downwind of Baltimore at 0900 contained 638 ppbC and a corresponding NO_x concentration of 60 ppb. Thus, a hydrocarbon/NO_x ratio of 10.5 was observed in the air mass departing Baltimore at 0900.

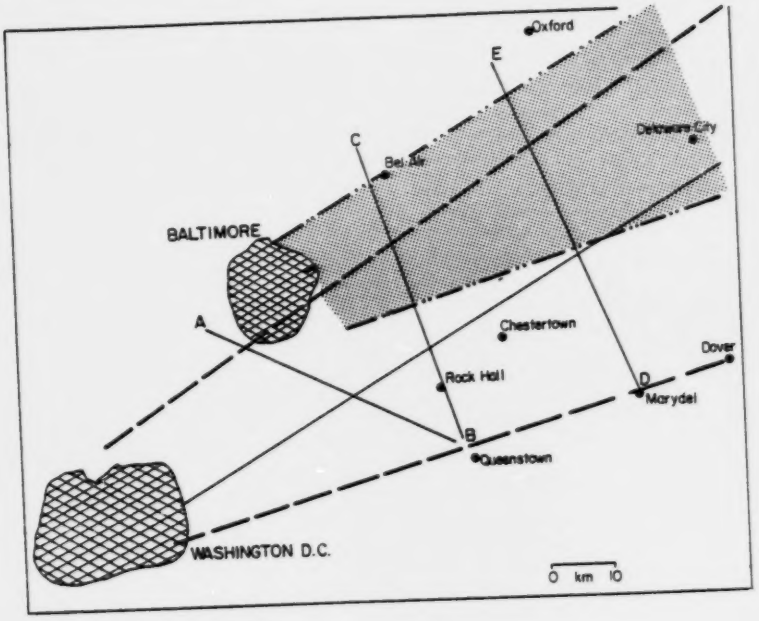
Figure 7b shows the crossplume ozone profiles recorded at each of the traverse locations denoted in Figure 7a. Upon scanning this figure, it is immediately obvious that highest ozone concentrations were recorded in the northern portion of the traverses. This corresponds to the stippled section in Figure 7a. No air mass tracer was employed so changes in ozone concentration with distance can not be analyzed in a Lagrangian sense. The ozone profiles shown in Figure 7b are representative of three different air parcels that passed over the two urban areas earlier in the day. Based on wind speeds described previously, the air parcel sampled at about 1700 100 km from Baltimore (traverse E-F) departed Washington, DC about 0900 and passed over and south of Baltimore about 1130. The air mass monitored 60 km downwind of Baltimore (traverse C-D) left Washington, DC about 1000 and passed the Baltimore region at 1230, while the air mass examined 20 km from Baltimore (traverse A-B) passed over Washington about noon and reached the sampling area about 1500.

Highest ozone levels were recorded along the E-F traverse. Peak concentrations exceeded 200 ppb in the region west of Wilmington, DE. An overall ozone plume width of approximately 130 km was observed along this track.

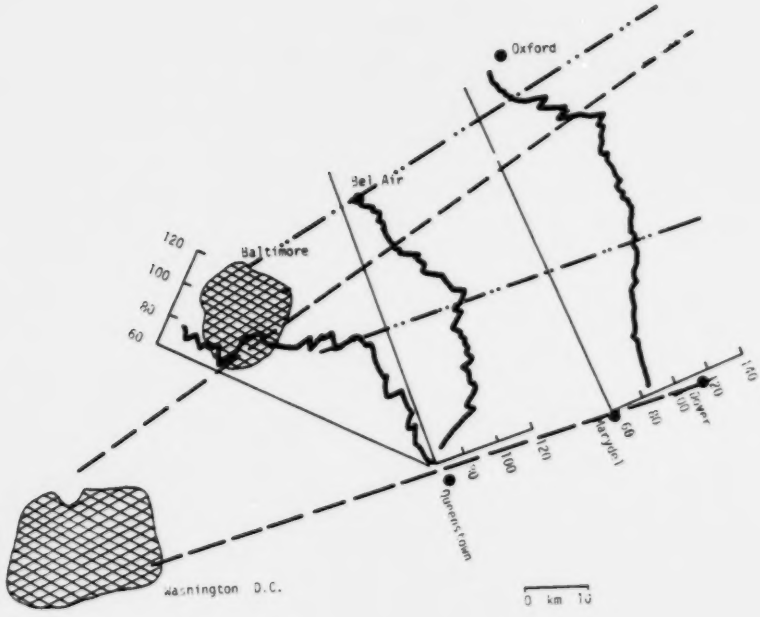
Background ozone concentrations to the north and south of the Baltimore-Washington, DC plume were about 100 ppb. Thus, a maximum ozone build-up of 100 ppb was recorded in this air parcel which left Washington, DC about 0900 and passed Baltimore before noon. Judging from the location and general shape of the E-F crossplume ozone profile, it would appear that the ozone levels in excess of 180 ppb observed west of Wilmington were primarily associated with Baltimore. There is a region in the middle of the traverse with ozone concentrations in the 140-170 ppb range which was influenced about equally by the two cities. In the most southerly section, the Washington plume exhibited ozone levels in the 110-130 ppb range. If this analysis is correct, the dashed lines included with the E-F traverse in Figure 7b represent a reasonable approximation of the source contributions to downwind ozone levels at points along this traverse.

Plume behavior similar to that described on July 19 was recorded on August 3. Winds out of the southwest carried Washington, DC emissions over and around Baltimore and into the region northeast of the two cities. Figure 8a shows boundaries of the oxidant plume and the location of aircraft sampling traverses. Maximum inplume ozone levels on the afternoon of August 3 were lower than those recorded during the afternoon hours of July 19. Wind speeds, afternoon mixing heights and solar intensities were very similar on the two days, however, considerably lower precursor concentrations were recorded during the morning hours of August 3. For example, nonmethane hydrocarbon levels in Baltimore averaged about 500 ppbC on August 3 as compared to 1170 ppbC on July 19. August 3 was a Sunday while July 19 fell on a Saturday.

Figure 8b shows ozone profiles recorded along aircraft traverses on



(a)



(b)

Figure 8. Map showing ozone plume characteristics downwind of Baltimore and Washington, DC on August 3, 1980.

August 3. An ozone bulge is readily apparent along the traverse (AB) upwind of Baltimore with maximum concentrations of about 110 ppb compared to background levels of 70 ppb. This air parcel had passed over Washington, DC two to three hours earlier (1000-1100). The ozone profile along a traverse 20 km downwind of Baltimore demonstrates little difference in the ozone pattern compared to that recorded upwind. Ozone concentrations are a little higher in the northern section of the 20 km downwind traverse which would correspond to the region most highly influenced by Baltimore, however, the general shape of the plume and the magnitude of ozone concentrations recorded along the two traverses are nearly identical. This implies that the ozone concentrations recorded aloft over Baltimore during the afternoon hours were primarily dictated by precursor emissions in Washington, DC. In other words, afternoon emissions in the Baltimore area have little effect on ozone concentrations in air parcels transported to a distance of 20 km downwind of the city center.

The crossplume ozone profile shown in Figure 9 was recorded on August 3 at a distance of 60 km downwind of Baltimore and approximately 110 km from Washington, DC (traverse DE in Figure 8). The air mass sampled in this traverse departed the Washington, DC area about 0900 and passed over Baltimore about noon. It is possible to establish the approximate centerline of the Washington, DC plume based on the two crossplume traverses described previously. This is denoted in Figure 8a as the solid line originating in Washington, DC. Based on measured plume boundaries and the approximate location of plume centerlines, ozone source contributions along the 60 km downwind traverse can be semi-quantitatively apportioned as shown in Figure 9. The dashed lines in this figure represent the hypothetical

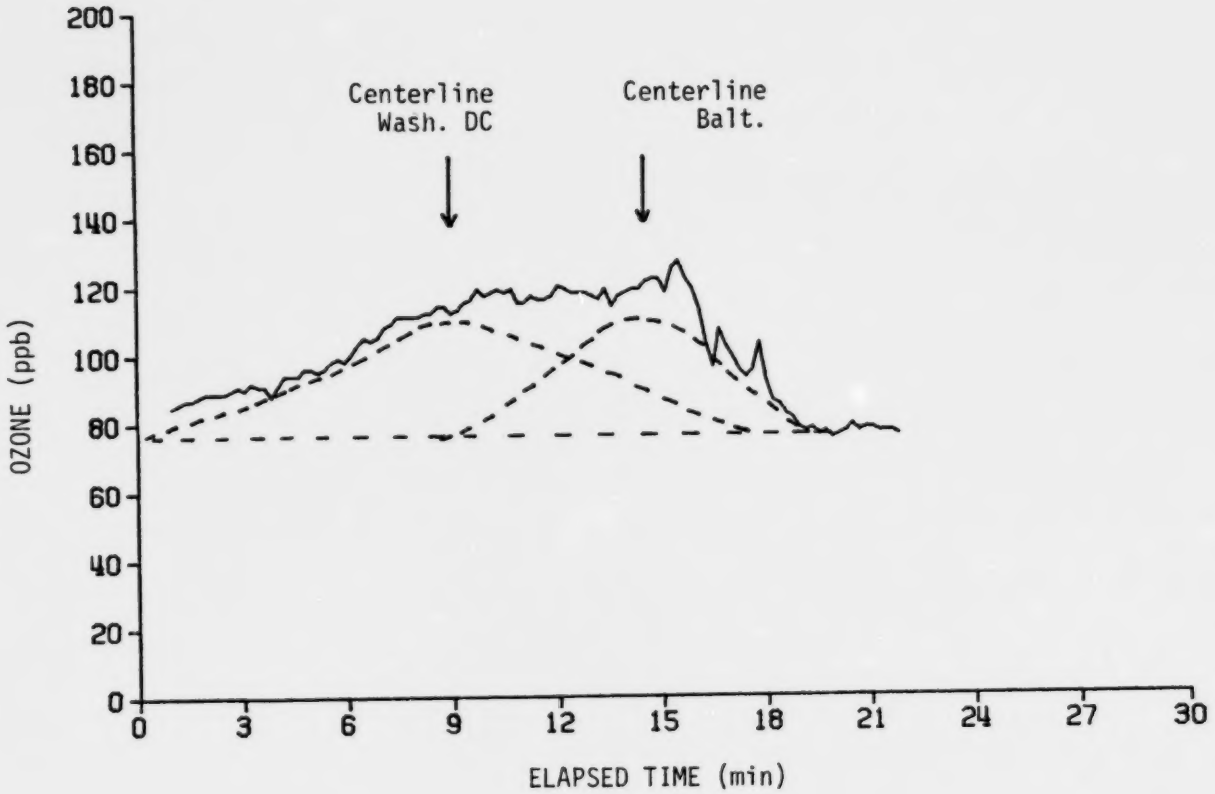


Figure 9. Cross-sectional ozone profile recorded in plume interaction region (traverse DE Figure 8) with hypothetical individual ozone plumes represented by dashed lines.

individual ozone plumes from the two cities. The maximum ozone concentration at the centerline point of the Washington plume was 112 ppb. This corresponds to an ozone buildup of 36 ppb (112-76 ppb). In the section of the plume influenced by both Washington, DC and Baltimore emissions, maximum ozone levels reached 123 ppb. Thus, the maximum ozone buildup in the combined plumes amounted to 47 ppb which represents a 30% increase over the Washington plume alone. This analysis implies that peak ozone levels in the two plumes would be nearly identical if they were separated from one another. The 30% excess ozone in the Baltimore plume is due to ozone produced from Washington, DC emissions. Between the centerlines of the two plumes, ozone levels remain fairly constant at about 115 ppb. The ozone concentrations between the plume centerlines can be viewed as a simple additive effect involving a varying contribution from each of the individual plumes.

The hypothesis that additivity accounts for ozone concentrations observed in the plume interaction region is supported by data collected on other days. For example, Figure 10 shows a crossplume ozone profile recorded on July 25 approximately 60 km to the east of Baltimore. Upper level winds on July 25 were more westerly which resulted in a side-by-side interaction of the two plumes. If the dashed lines in Figure 10 are used to represent the individual ozone plumes, it can be seen that ozone concentrations in the overlap region are commensurate with the levels expected by adding the contribution from each of these plumes.

Plume Dimensions

Due to the varying degrees of interaction between the two plumes, ozone concentration profiles across the combined Washington, DC - Baltimore plume were seldom symmetrical (Gaussian). As indicated previously, highest

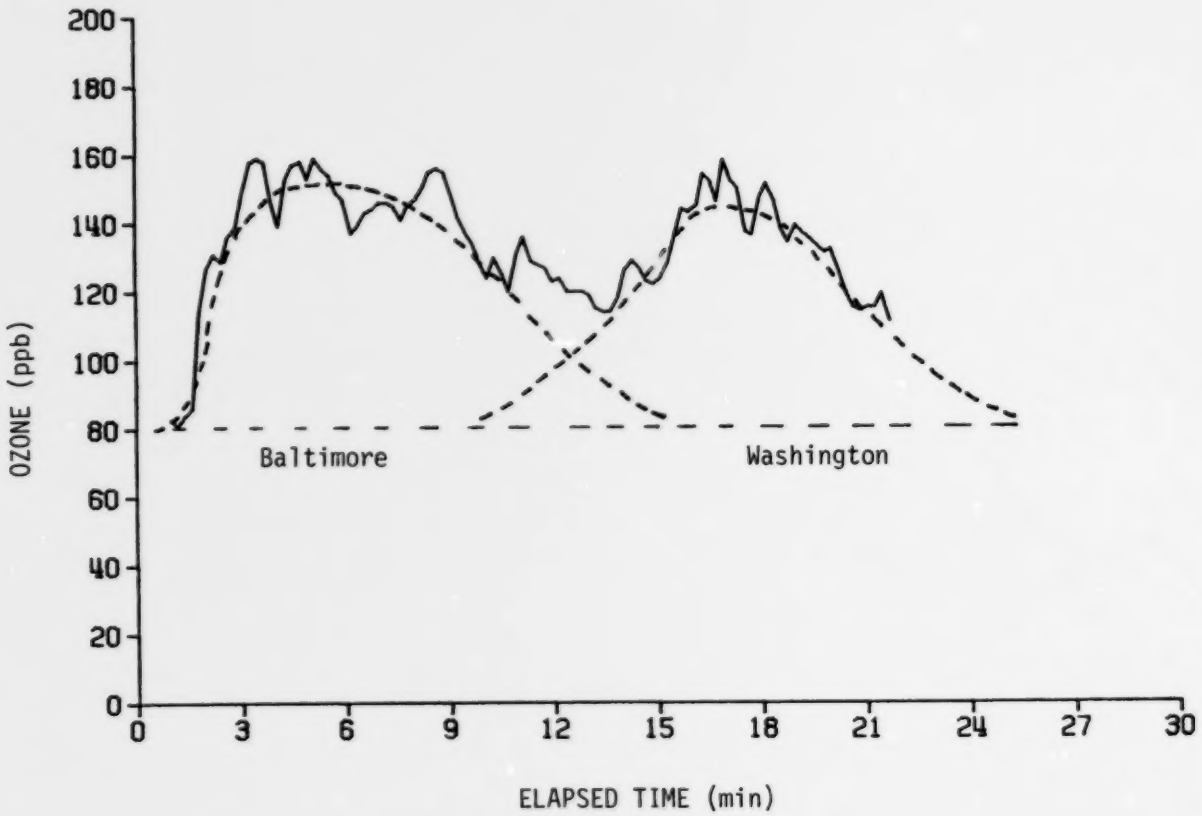


Figure 10. Crossplume ozone profile recorded 60 km downwind of Baltimore and ~ 115 km downwind of Washington, DC at 3000 ft. on July 25, 1980. Dashed lines represent individual plumes.

ozone levels were normally observed in the region of maximum overlap which resulted in a crossplume ozone gradient with highest concentrations in the northern portion of the plume and lower levels to the south. On a few occasions, exceptions to this general behavior were observed, especially, in the vicinity of Havre De Grace which is located about 60 km from Baltimore near the northern end of Chesapeake Bay. Figures 11 and 12 illustrate this atypical behavior. A narrow band of high ozone is present in the 1500 ft profile shown in Figure 11 while the northern section of the traverse shown in Figure 12 exhibits abnormally high ozone levels and a very extreme demarkation between the background and polluted air masses. Reasons for the unusual ozone behavior in the vicinity of Havre De Grace are probably associated with the presence of Chesapeake Bay. Surface hydrocarbon and NO_x emissions that drift downwind over the Bay could remain near the surface due to reduced vertical mixing over the water. This would effectively concentrate the ozone precursors in a shallow layer which would tend to produce high ozone concentrations as the day progressed. Furthermore, it is expected that ozone losses due to surface scavenging mechanism would be reduced during overwater travel. The high ozone band shown in Figure 11 was indeed confined to the portion of the ozone plume that was situated over Chesapeake Bay South of Havre De Grace. A back trajectory analysis, based on winds in the 1000-3500 ft layer, indicates that this air parcel passed over Washington, DC during the 0700-0800 period on August 5 and then traveled in a northeasterly direction over Chesapeake Bay and into the Havre De Grace area. A buildup in ozone concentrations along the northern shoreline of Chesapeake Bay, as exemplified by the profile shown in Figure 12, very likely results from onshore advection of ozone rich air by sea breeze winds.

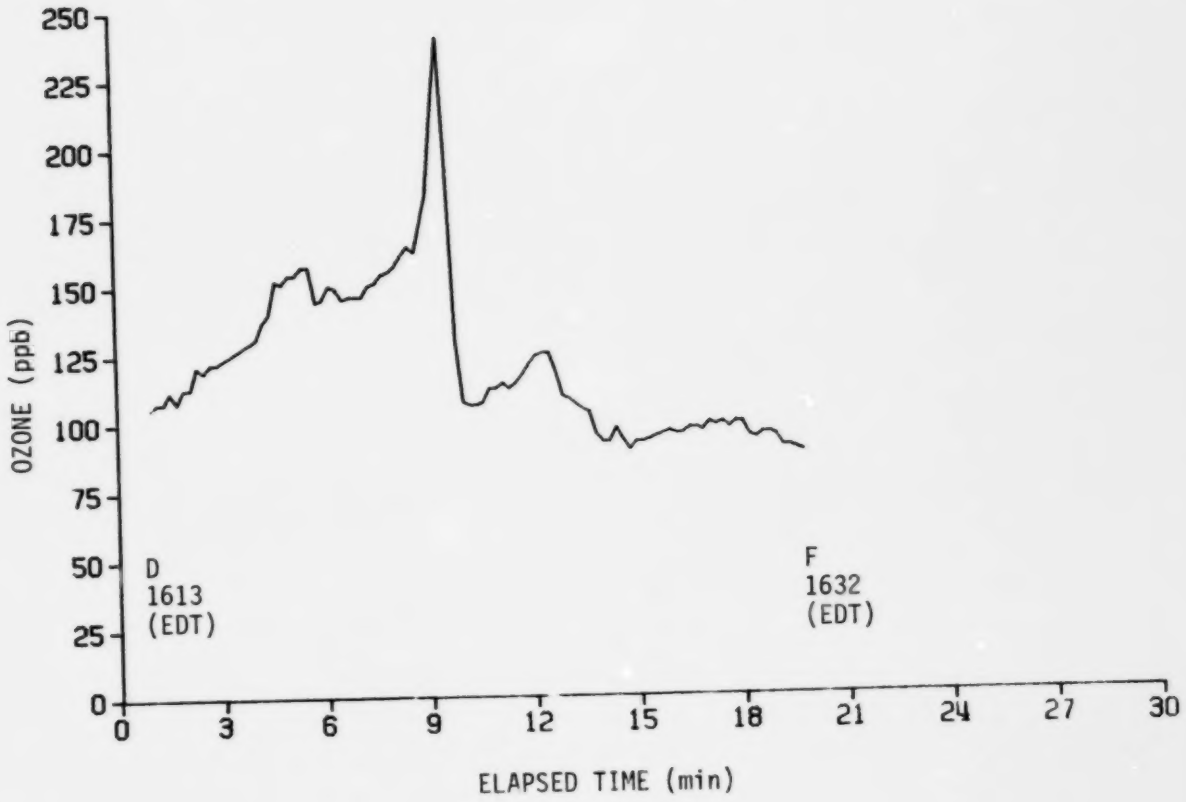


Figure 11. Crossplume ozone profile recorded 60 km downwind of Baltimore at 1500 ft on August 5, 1980 (see Figure F-2 for traverse location).

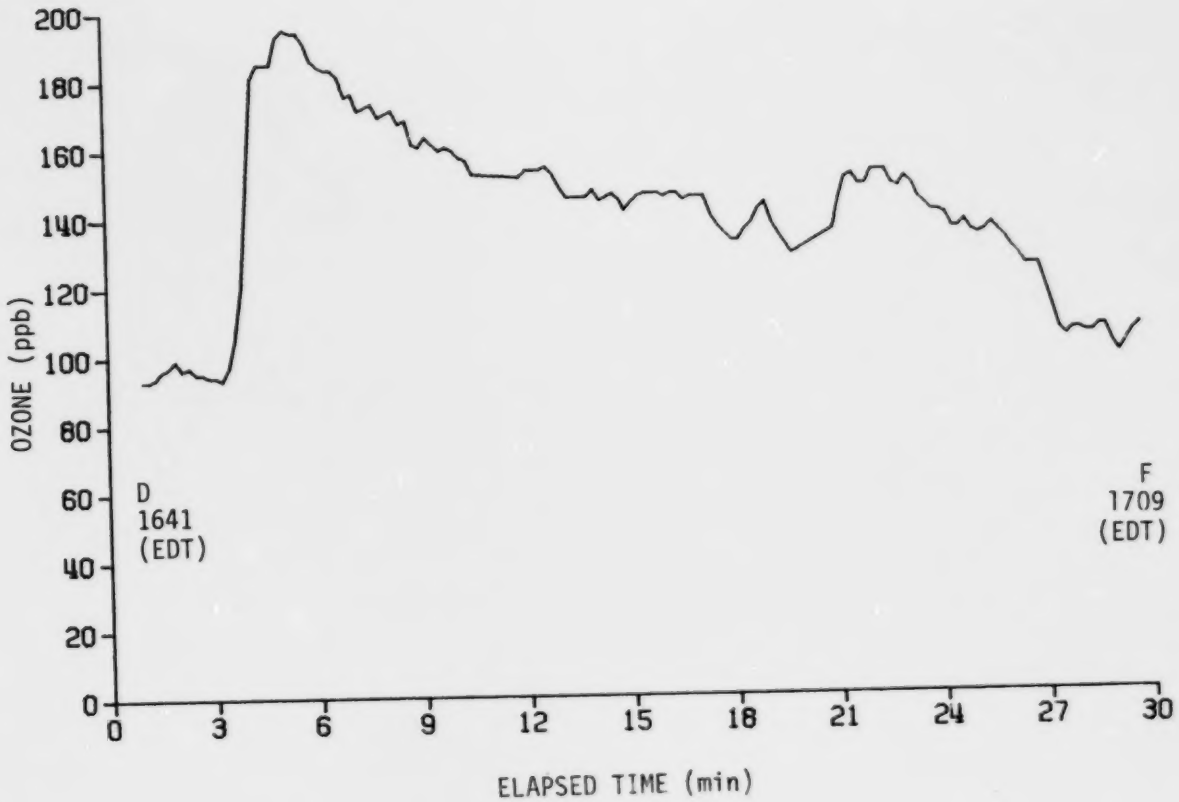


Figure 12. Crossplume ozone profile recorded 60 km downwind of Baltimore at 1000 ft on July 19, 1980 (see Figure A-5 for traverse location).

This type of behavior has been documented along the western shore of Lake Michigan and in the region downwind of New York City along the Connecticut coastline (6,7).

Vertical and horizontal dimensions of the combined Washington, DC - Baltimore plume on each of the seven study days are described in the Case Studies Section (Appendices A - G) of this document. During the afternoon hours elevated ozone levels generally blanketed the region between Washington, DC and Wilmington, DL with the north-south boundaries of the ozone plume being dependent on the relationship between wind direction and the geographical location of Baltimore and Washington, DC. The upper boundary of the ozone plume usually increased from less than 2500 ft during the morning hours to about 5000 ft by late afternoon. Vertical ozone patterns at a fixed distance downwind of the two cities varied from day to day. Therefore, it is difficult to establish generalized vertical ozone patterns within the plumes. However, as indicated previously, it does appear that highest levels occur closest to the surface in the region around the northern tip of Chesapeake Bay. Figure 13 shows the crossplume ozone pattern recorded at 2500 ft along the same track as the 1000 ft profile shown in Figure 12. Maximum ozone concentrations at 1500 ft approached 200 ppb while those at the higher altitude were in the 170 ppb range. At distances of 80-100 km from Baltimore (Wilmington, DL region), a more normal vertical ozone pattern was observed with highest levels occurring at intermediate altitudes (2500-3000 ft) and lower concentrations above (4500 ft) and below (1500 ft).

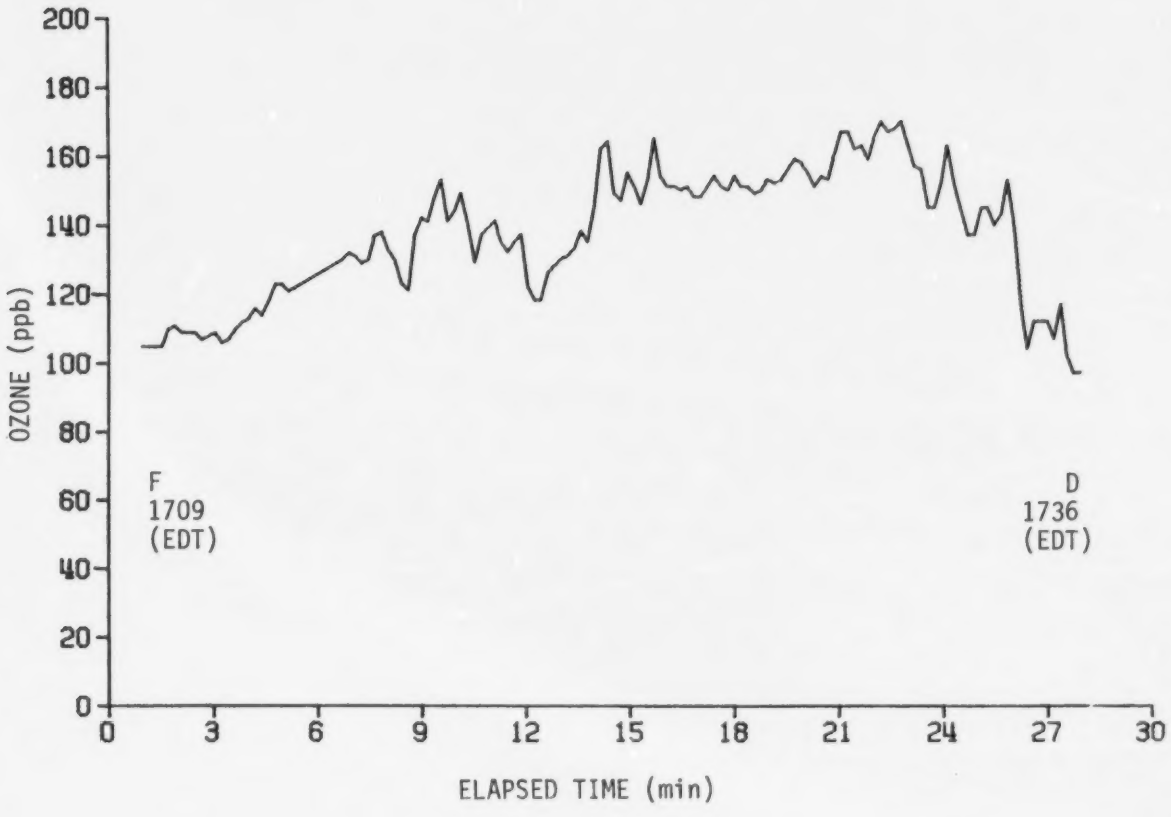


Figure 13. Crossplume ozone profile recorded 60 km downwind of Baltimore at 2500 ft on July 19, 1980 (see Figure A-5 for traverse location).

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APPENDIX A

Data Summary and Analysis

July 19, 1980

On this day, a westward extension of the Bermuda High influenced weather conditions in the Baltimore-Washington, DC area. Clear skies were reported most of the day with scattered cumulus clouds during the afternoon. Winds were from the southwesterly direction all day. The temperature near the surface was 25-30°C. A strong inversion was detected early in the morning at a height of 250 m; in the afternoon, a weak inversion was present at 1400 m above the surface (8,9).

The early morning surface inversion appeared to breakup about 1000 (EDT) as evidenced by a rapid raise in the surface ozone concentration. As shown in Figure A-1, this jump in O_3 concentration was accompanied by a corresponding decrease in the ground level NO_x concentration. Afternoon mixing levels, as measured by aircraft soundings varied from about 3000' to 5000'. An aircraft vertical spiral 20 km downwind of Baltimore about noon showed elevated O_3 levels up to about 3000'. Vertical soundings at greater distances downwind during the late afternoon hours exhibited ozone buildup to approximately 5000'.

Figure A-2 shows the trajectory predicted for an air parcel leaving Washington at 0800 on July 19. The trajectory passes over Baltimore at 1100 and continues in a northeastward direction with arrival of the original air parcel in the Wilmington, DE area about 1800.

Four flights were conducted during the morning and afternoon hours on July 19. The BNL and WSU aircrafts flew traverses perpendicular to the wind flow at points upwind and 20 to 60 km downwind during the morning hours. Afternoon flights were designed to monitor ozone buildup in the region 20-90 km downwind of Baltimore.

BNL flight #1 (0714-1102) - Aircraft traverses normal to the southwesterly wind direction were made at points about 20 km upwind and at 20 and 60 km

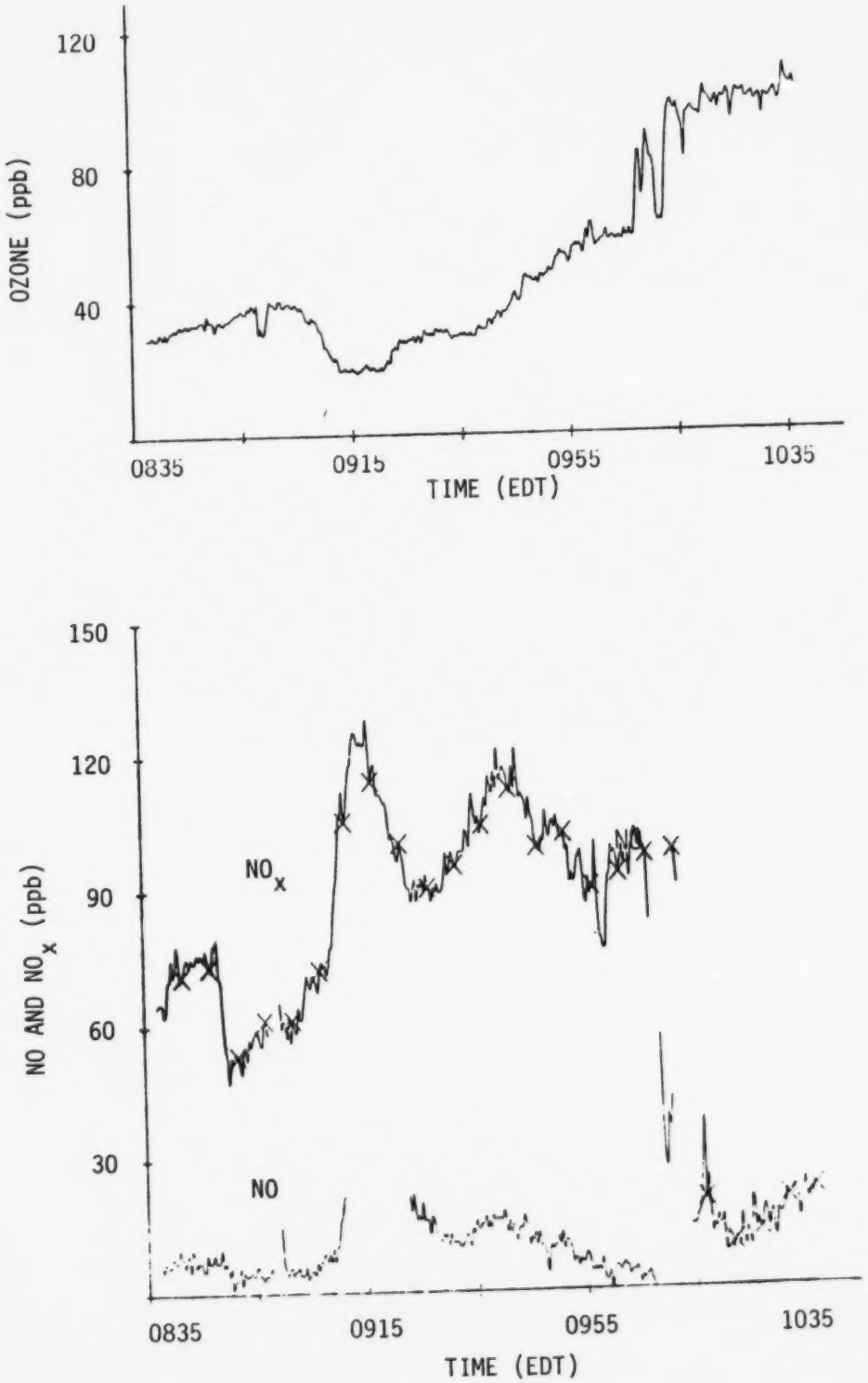

Figure A-1. Ground level ozone and NO_x concentrations recorded 20 km downwind of Baltimore on July 19, 1980

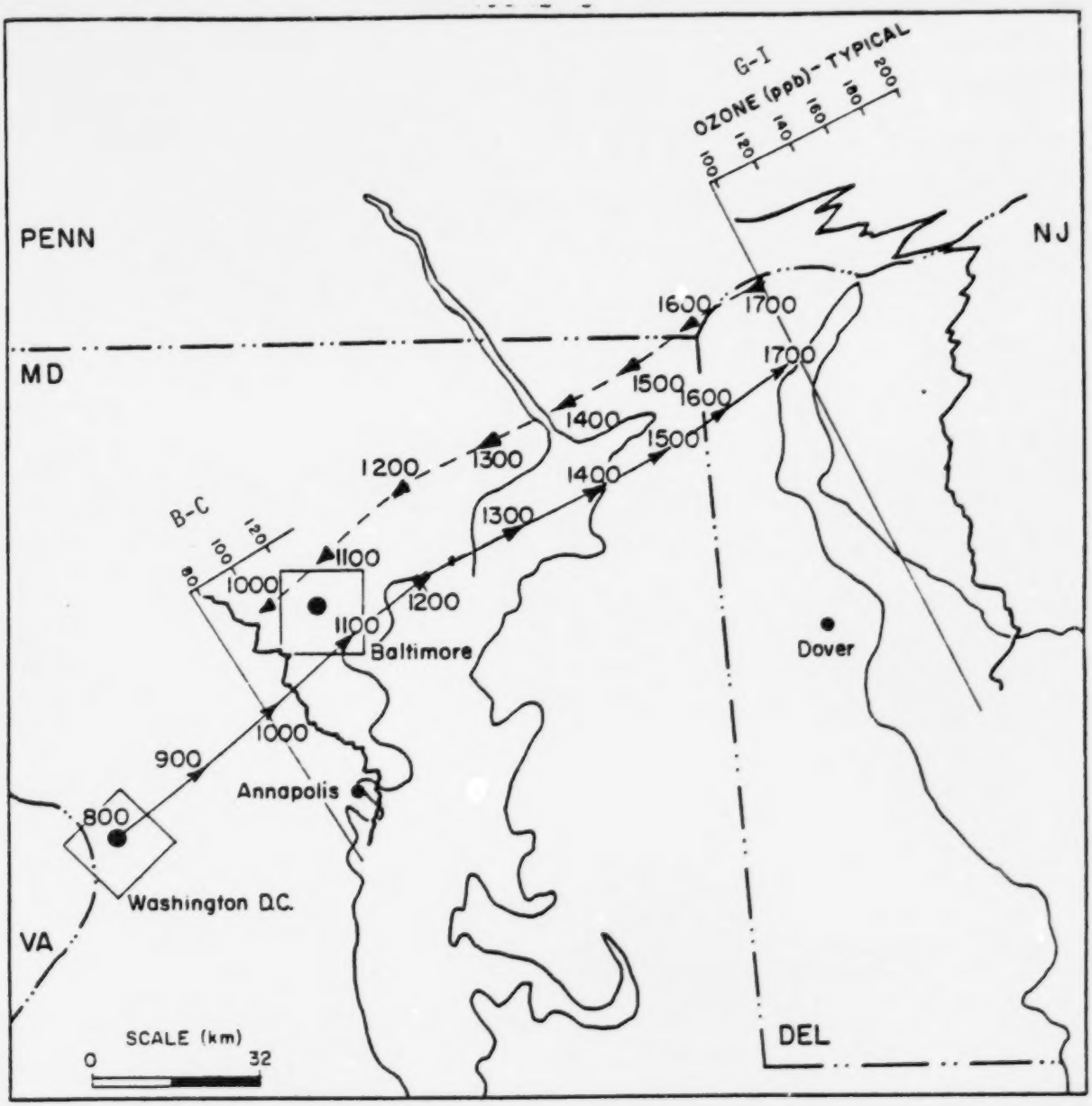

Figure A-2. Forward (——►) and backward (◄——) air mass trajectories and ozone crossplume profiles (BC - 2000', 0932-0947; GI - 2500', 1745-1812) on July 19, 1980.

downwind of Baltimore. The flight route is shown in Figure A-3. The upwind traverse which was flown at 2500' showed very constant ozone levels of 70-75 ppb. No evidence of plumes can be seen in the O_3, NO_x, SO_2 or B_{scat} data recorded along this upwind leg. The aircraft next made traverses at 1000' and 3000' approximately 20 km downwind of the Baltimore City Center. Elevated NO_x, SO_2 and B_{scat} readings together with slightly depressed O_3 levels were observed during the 1000' traverse.

There was little evidence of Baltimore emissions at 3000'. In the northern section of the traverse, B_{scat} levels increased to a maximum of 3.0×10^{-4}/m from the background readings of about 2.0×10^{-4}/m. In this same portion of the traverse, O_3 levels were depressed by about 10 ppb compared to the mean value of 65 ppb.

The O_3 profiles shown in Figure A-4 were recorded along the traverse 60 km downwind of Baltimore. At 2500', there is a region toward the northern end of the traverse where ozone enhancement can be seen. Peak concentrations approached 90 ppb which was about 25 ppb above the mean value recorded along the traverse. This ozone buildup was not observed at 1000' and, as can be seen in Figure A-4, O_3 levels were somewhat depressed in the section of the traverse where elevated O_3 concentrations were recorded at 2500'. Examination of the NO_x traces shows increased NO_x levels at 1000' in the region where depressed O_3 values were recorded. Thus, at 60 km downwind of Baltimore ozone production had begun at the uppermost levels of the Baltimore plume but not in the region between the surface and 1000', due perhaps to fresh surface emissions.

WSU flight #1 (0920-1207) - The WSU morning flight path was similar to that flown by the BNL aircraft with crosswind traverses at points 20 km upwind and 20 and 60 downwind of Baltimore. The upwind traverse was flown at 2000'.

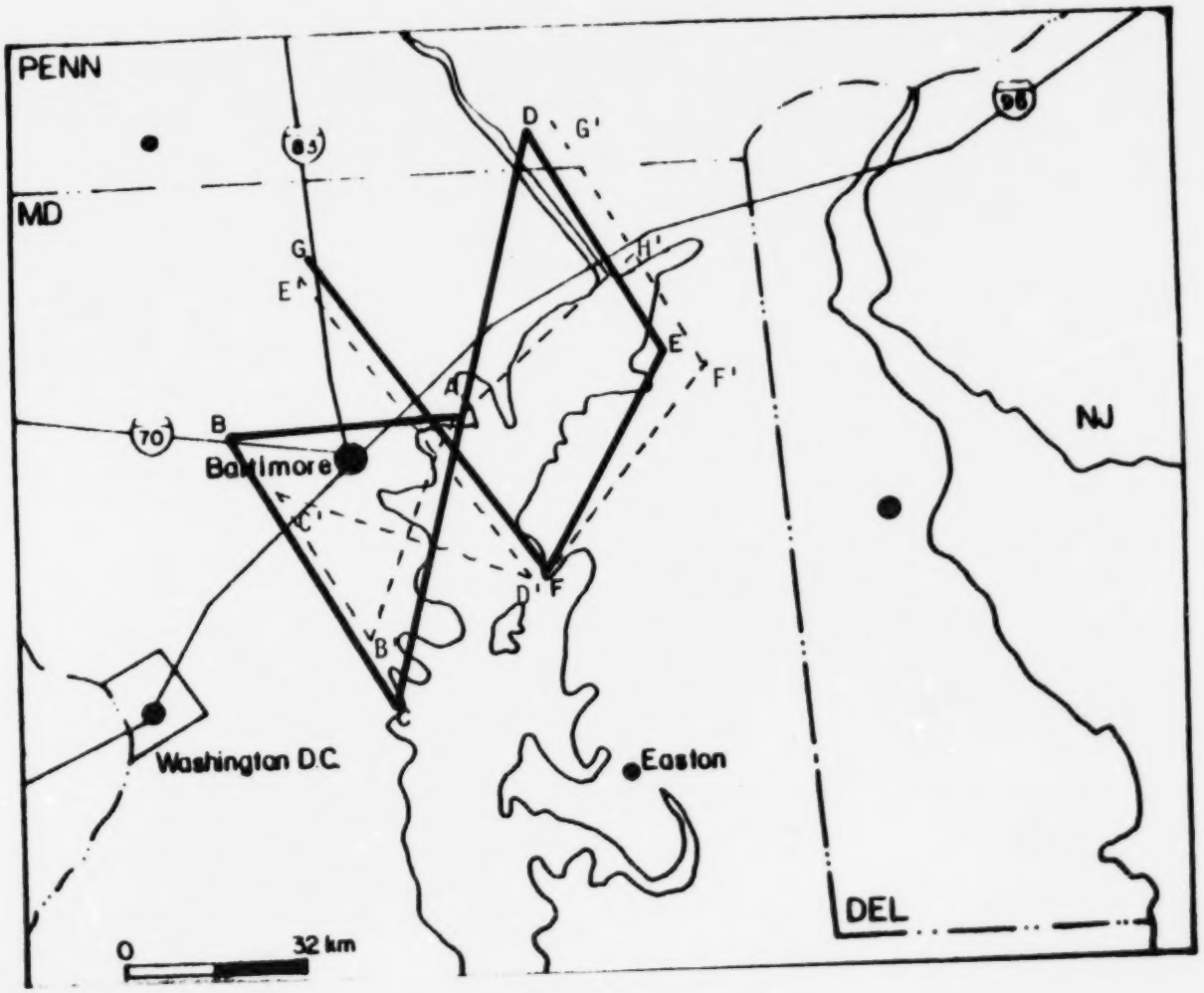

Figure A-3. July 19 morning flight paths.

BNL #1 (dashed line)			WSU #1 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
B'-C'	2500	0732-0741	A-B	2000	0920-0932
C'-D'	2800	0820-0834	B-C	2000	0932-0947
D'-E'	1000	0835-0850	C-D	2500	0948-1026
E'-D'	3000	0854-0912	D-E	2500	1026-1103
F'-G'	1000	0934-0952	E-F	2500	1103-1113
G'-F'	2500	0954-1015	F-G	3000	1114-1142
F'-H'	6000	1022-1031	G-A	1000	1143-1150
H'-A	1000	1045-1059			

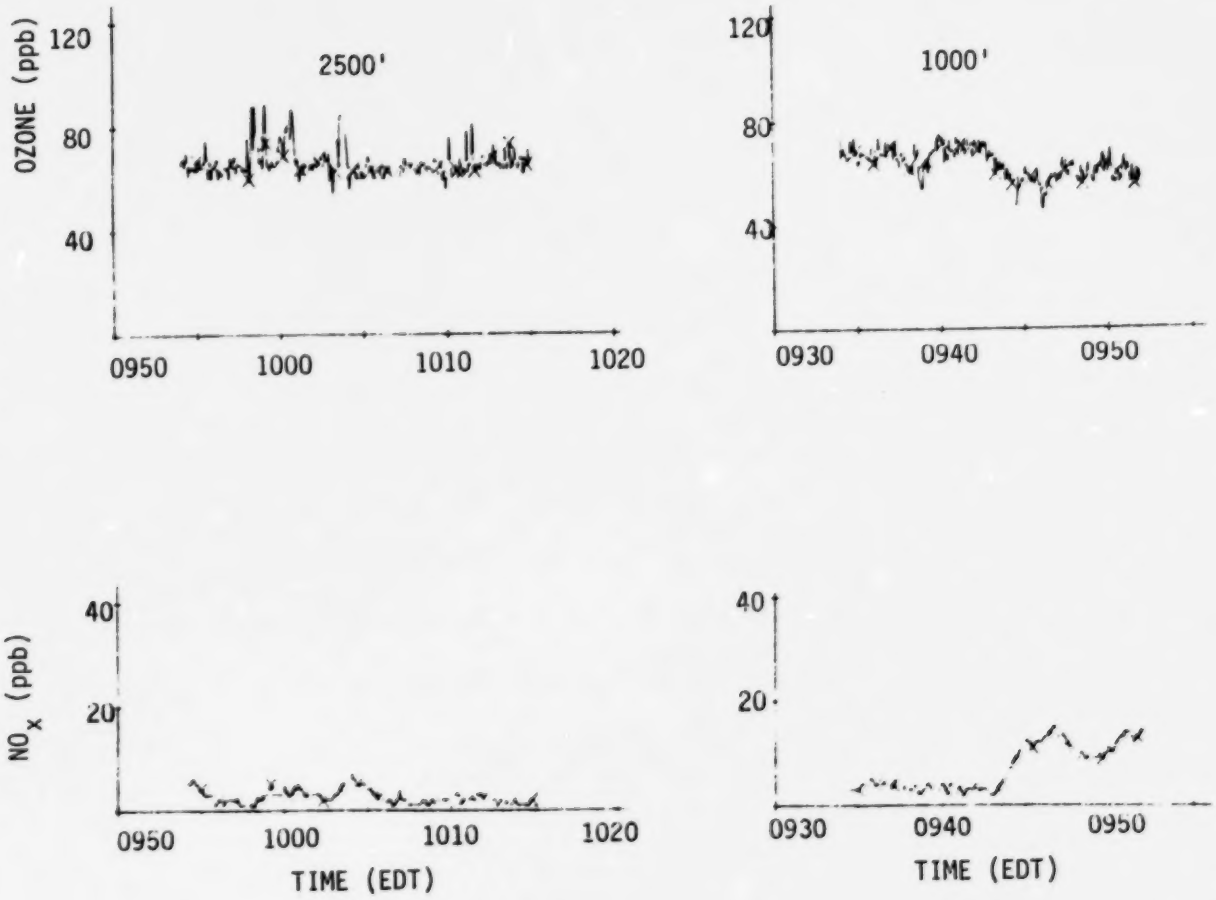

Figure A-4. Crossplume ozone and NO_x profiles recorded 60 km downwind of Baltimore at 2500 ft and 1000 ft on July 19, 1980 by BNL aircraft.

The O_3 levels upwind of Baltimore were in the 80-85 ppb range. This corresponds to a 10 ppb increase over the values record by the BNL aircraft two hours earlier. There is evidence of an ozone plume in the southern section of the traverse which most likely is attributable to emission from Washington, DC. Ozone levels peaked at about 110 ppb in this region downwind of Washington.

After completing the upwind traverse, the WSU aircraft proceeded eastward in preparation for the 60 km downwind traverse. The O_3 levels at 2500' along the northern half of the traverse were between 90 and 100 ppb with no evidence of a well defined ozone plume. A vertical sounding to 6000' was performed at the midpoint of this traverse (over Havre De Grace). O_3 concentration decreased from the 90-100 ppb observed at altitudes below 3000' to about 70 ppb at 6000'. Near Crystal Beach at the southern extremity of the 60 km downwind traverse, an ozone bulge approaching 120 ppb was observed. The airplane next turned toward the southwest and proceeded inbound toward the urban centers for a 20 km downwind traverse. This pass downwind of Baltimore and Washington showed evidence of separate ozone plumes from the two cities. Ozone concentrations at 2500' on the southern edge of the WDC plume were about 100 ppb and increased to 120 ppb in the middle of the plume. An ozone plume northeast of Baltimore exhibited maximum ozone levels in the 110-115 ppb range at 3000'. A pass back across the Baltimore plume at 1000' showed levels approaching 140 ppb directly east of the city.

BNL flight #2 (1322-1617) - Plume traverses at distances of 20 and 60 km downwind of Baltimore were performed by the BNL aircraft during this afternoon flight (Figure A-5). At the 20 km distance, ozone plumes were observed at 1000' and 2500' as shown in Figure A-6. An ozone plume is

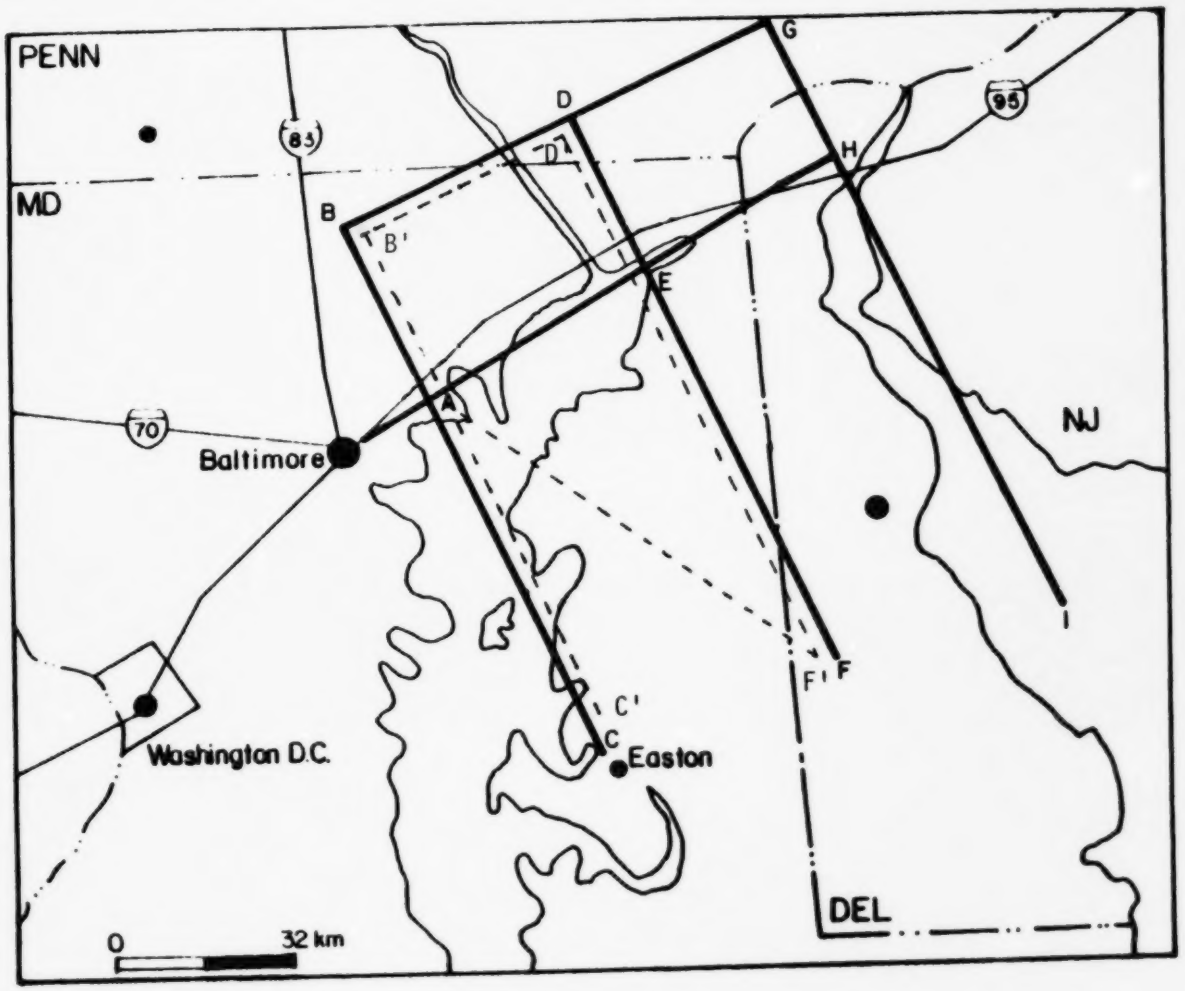

Figure A-5. July 19 afternoon flight paths.

BNL #2 (dashed line)			WSU #2 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B'	4500	1353-1402	A-B	4500	1530-1540
B'-C'	2500	1407-1435	B-C	2500	1541-1607
C'-B'	1000	1438-1504	C-B	1000	1608-1632
D'-F'	1000	1518-1550	D-F	1000	1641-1709
F'-A	2500	1553-1614	F-D	2500	1710-1736
			G-I	2500	1745-1812
			I-H	2500	1812-1837
			H-A	2500	1837-1858

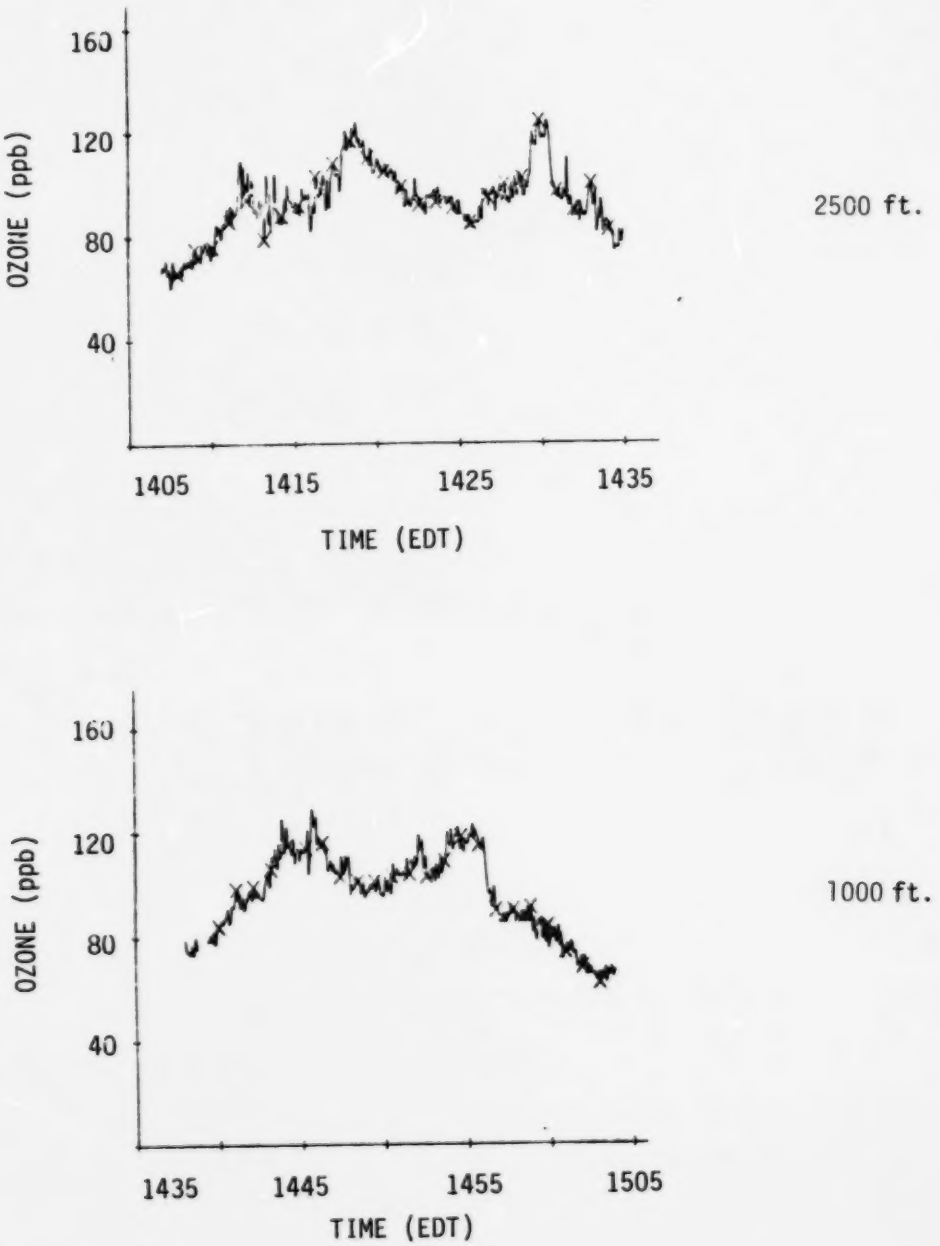

Figure A-6. Crossplume ozone profiles recorded 20 km downwind of Baltimore at 1000 ft and 2500 ft on July 19, 1980 by BNL aircraft.

clearly evident from both Baltimore and Washington, DC. Data recorded on the 2500' traverse show background O_3 levels to the north and south of the plumes of about 80 ppb and nearly identical maximum in the two plumes of 120 ppb. In the region of overlap between the plumes, ozone concentrations are in the 100 ppb range. Further downwind at the 60 km distance, the airborne measurements show an ozone bulge approximately 30 km wide in the northern section of the traverse and a broad ozone plume about 40 km in width to the south. Maximum ozone concentrations in the northern portion of the plume were about 120 ppb compared to a peak of 100 ppb in the south.

WSU flight #2 (1515-1858) - The WSU aircraft made crosswind passes at distances of 20, 60 and 100 km downwind of Baltimore during the afternoon hours of July 19. Figure A-7 shows the ozone pattern recorded along the 20 km traverse at 1000' elevation. A bimodal ozone plume was observed with peak concentrations of approximately 160 ppb in the central portion of each plume. Figure A-8 shows the ozone concentrations recorded along the 60 km downwind traverses at 1000 and 2500'. Ozone concentrations in the northern section of the plume increased to greater than 180 ppb. The peak O_3 values recorded in the southern portion of the plume decreased about 10 ppb to about 150 ppb. There is obviously a greater degree of overlap between the Washington, DC and Baltimore plumes at this distance as compared to that observed at 20 km from Baltimore. Ozone concentrations are elevated over nearly the entire length of the crosswind traverse. As can be seen in Figure A-9, the crosswind O_3 profile at a distance of 100 km from Baltimore shows a broad bulge in the northern section of the traverse peaking near 200 ppb with no plume discrimination. The O_3 concentrations in the southern portion of the traverse are generally below 140 ppb. Thus comparing these ozone values to those along the 60 km traverse, the Baltimore portion of

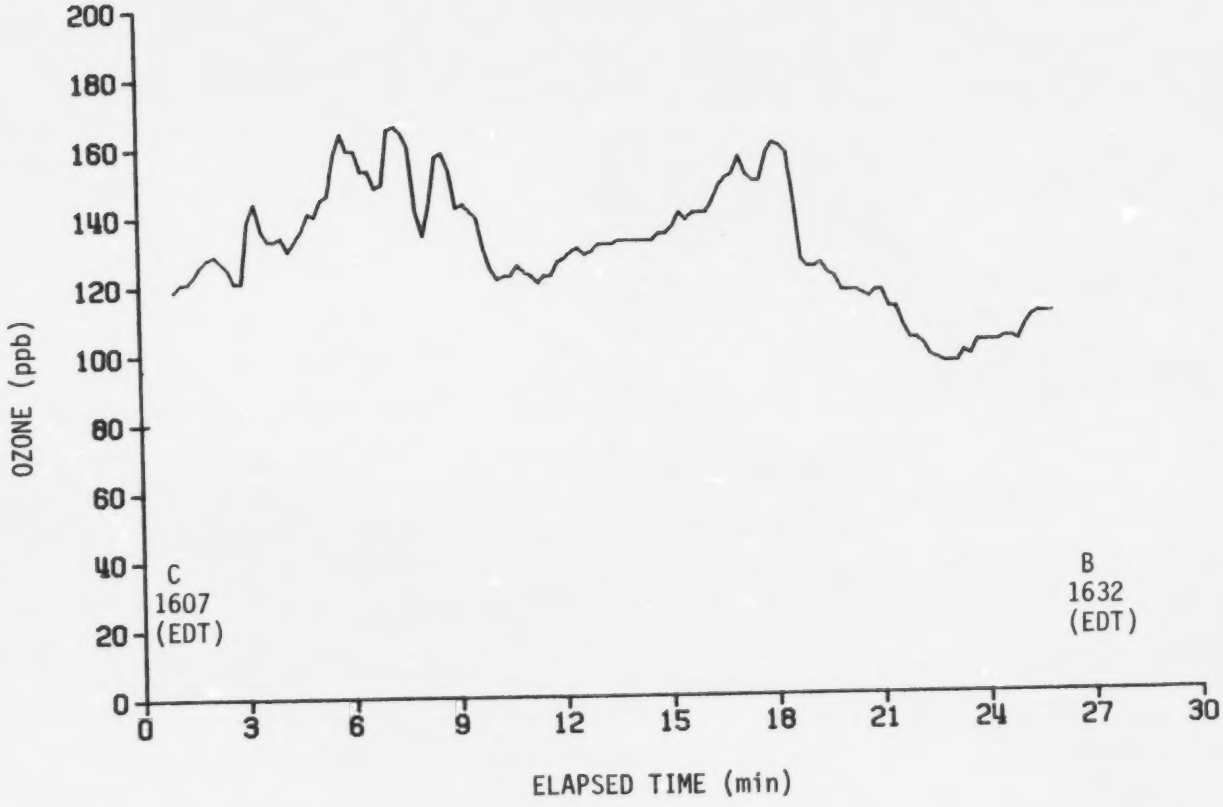

Figure A-7. Crossplume ozone profile recorded 20 km downwind of Baltimore at 1000 ft on July 19, 1980 by WSU aircraft.

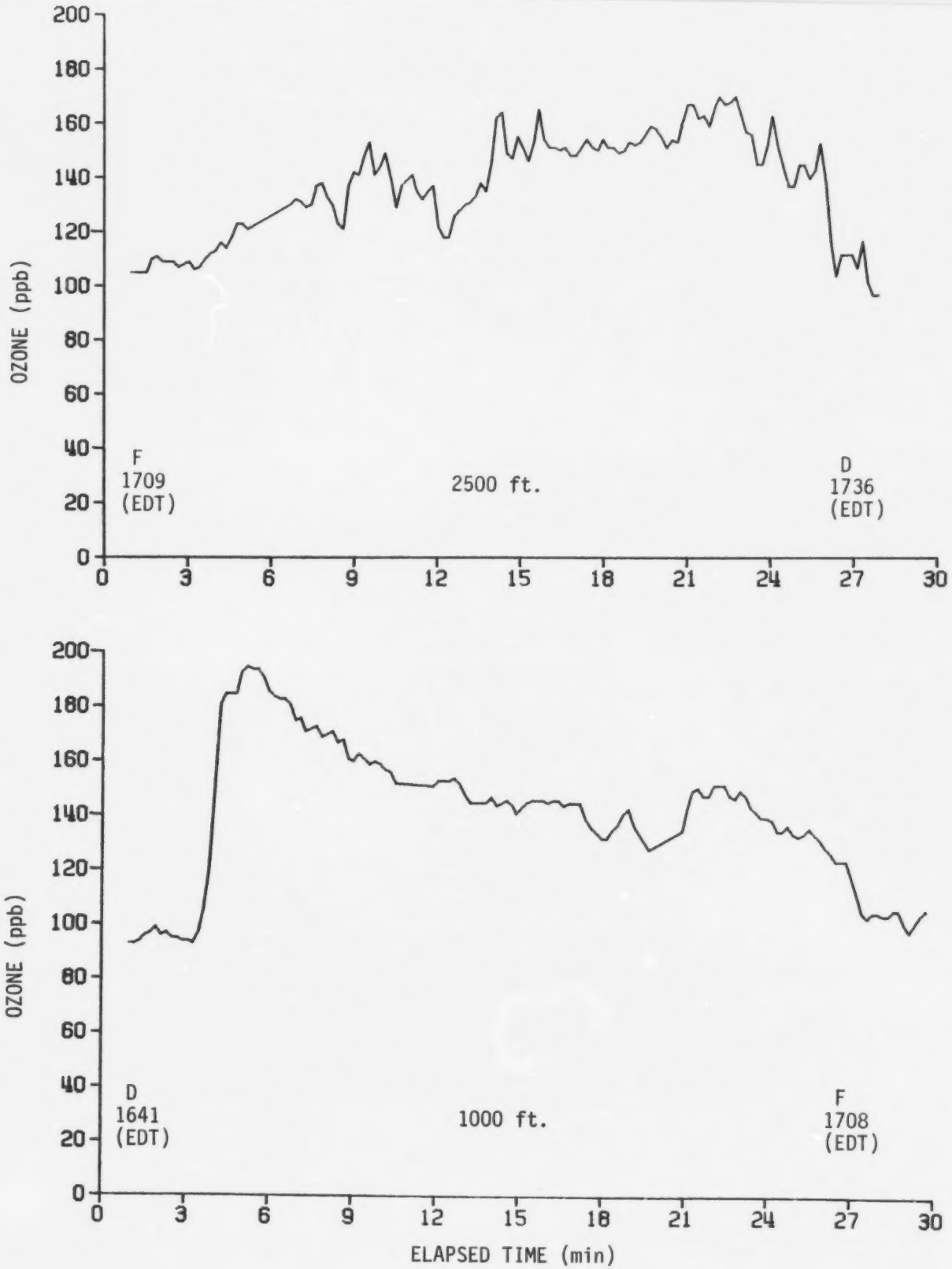

Figure A-8. Crossplume ozone profiles recorded 60 km downwind of Baltimore at 1000 ft and 2500 ft on July 19, 1980 by WSU aircraft.

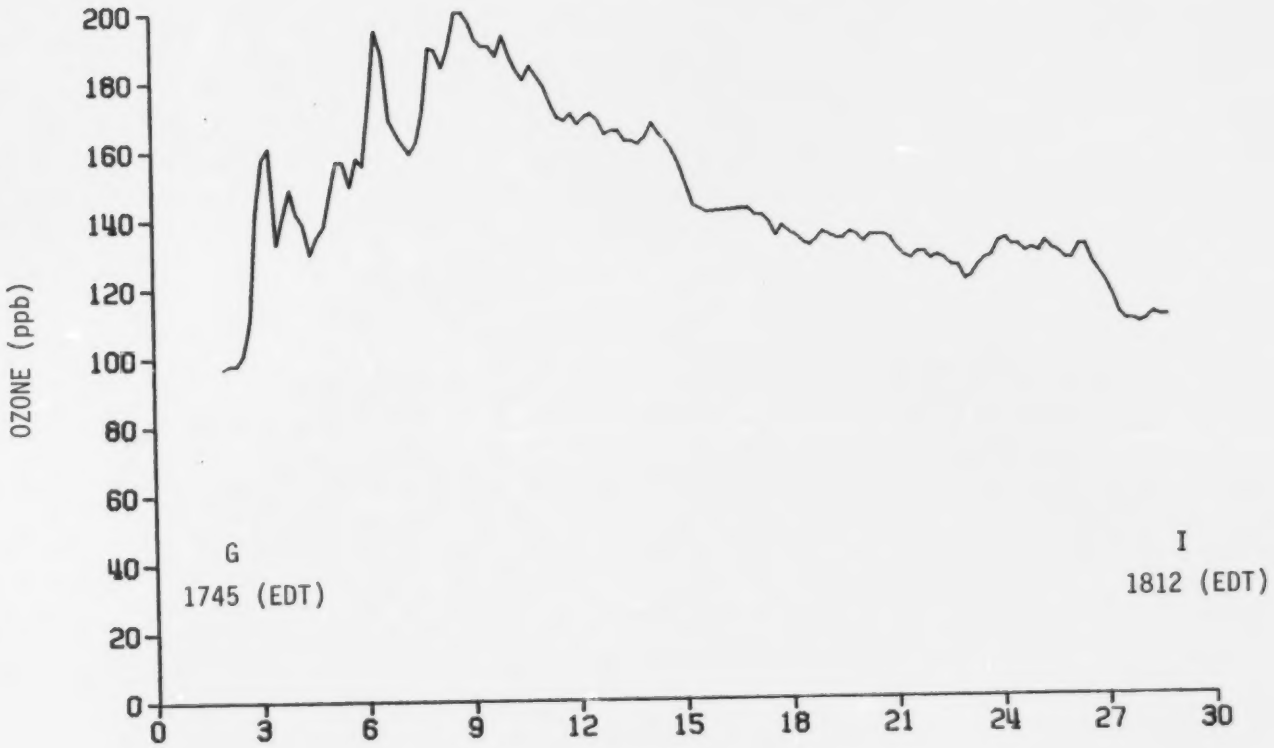

Figure A-9. Crossplume ozone profile recorded 100 km downwind of Baltimore at 2500 ft on July 19, 1980 by WSU aircraft.

the plume has increased from about 170 ppb to 200 ppb and those in the WDC plume have decreased from 140 to 130 ppb. This assumes that the Baltimore and WDC plume have not merged at the 100 km distance which may not be true.

The ozone pattern downwind of Baltimore and Washington at 2500' on the afternoon of July 19 can be summarized as follows. Peak O_3 concentrations in the northern section of the plume increase from 160 ppb at 20 km downwind to 170 ppb at 60 km and finally to 200 ppb at 100 km from Baltimore. Highest ozone concentrations in the southern portion of the plume were observed during the pass 20 km downwind of Baltimore (75 km from WDC). Peak concentrations at 60 and 100 km (115 km and 165 km from WDC) decreased by about 10 and 20 ppb, respectively.

APPENDIX B

Data Summary and Analysis

July 21, 1980

Three flights were conducted between the hours of 0900-1900 EDT. The BNL aircraft surveyed the region downwind of Baltimore during the time period between about 0900 and 1300. WSU's flight missions were performed during the late morning and midafternoon hours. All three flight routes were concentrated in the region between 20 and 80 km downwind of Baltimore. The temperature reached 101°F during the afternoon hours and it was hazy throughout the day. Winds were from the south-southwest at the surface while a more westerly flow prevailed aloft (8). The early morning mixing depth appeared to be below 2000' (9). A layer containing elevated ozone concentrations (~80 ppb) was present at altitudes between 2000 and 3500'. Above 4000', O_3 levels were in the 40-50 ppb range. During the afternoon hours, mixing occurred between the surface and about 4000' (9).

BNL flight #1 (0847-1252) - Cross plume traverses were flown at several altitudes in the region 20-60 km downwind of Baltimore (Figure B-1). There was no indication of an ozone plume 20 km from Baltimore at altitudes between 1500 and 4500'. At 1500', ozone concentrations were in the 50-60 ppb range. The crosswind traverse at 2500' revealed ozone concentrations in the 70-80 ppb range. Ozone levels were depressed (<40 ppb) in the region directly downwind of Baltimore. Ozone concentrations along the 40 km downwind traverse were in the 70-80 ppb range at 3000' and varied from 60 to 80 ppb at 1500'. Due to flight restrictions over the Aberdeen Military base, the 40 km traverse was limited to a region south of the main area of plume drift. A 2500' transect at 60 km revealed ozone levels approaching 100 ppb at the northern extremity and concentrations of about 70 ppb at the most southerly point. The ozone profile decreased gradually from north to south with no real clear evidence of individual plumes.

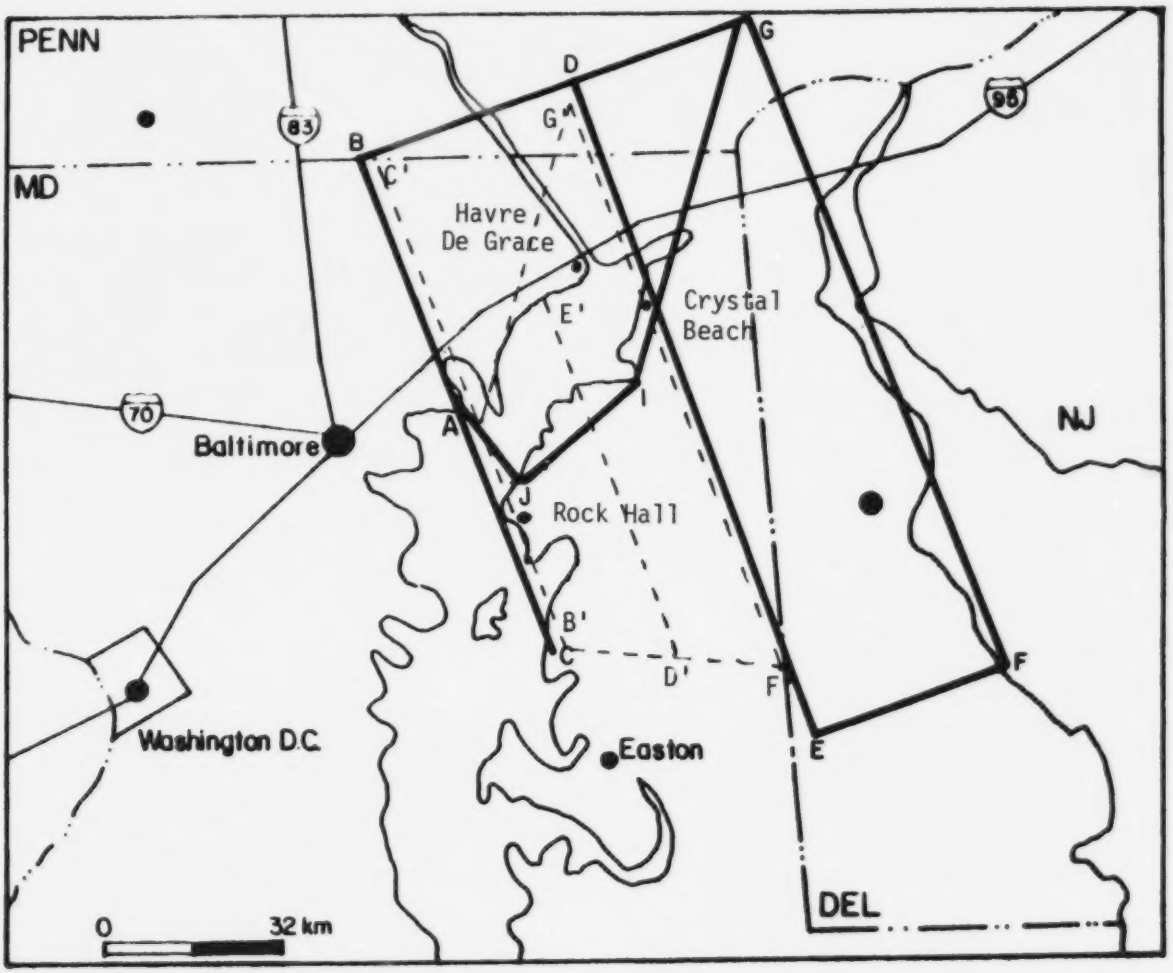

Figure B-1. July 21 morning flight paths.

BNL #1 (dashed line)			WSU #1 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B'	1500-6000	0923-1000	A-B	4500	1100-1113
B'-C'	2500	1004-1033	B-C	3000	1114-1135
C'-B'	4500	1041-1103	C-B	1500	1136-1201
D'-E'	3000	1110-1128	D-E	1500	1210-1244
E'-D'	1500	1131-1148	F-G	1500	1247-1320
F'-G'	2500	1156-1230	G-A	1500	1321-1352

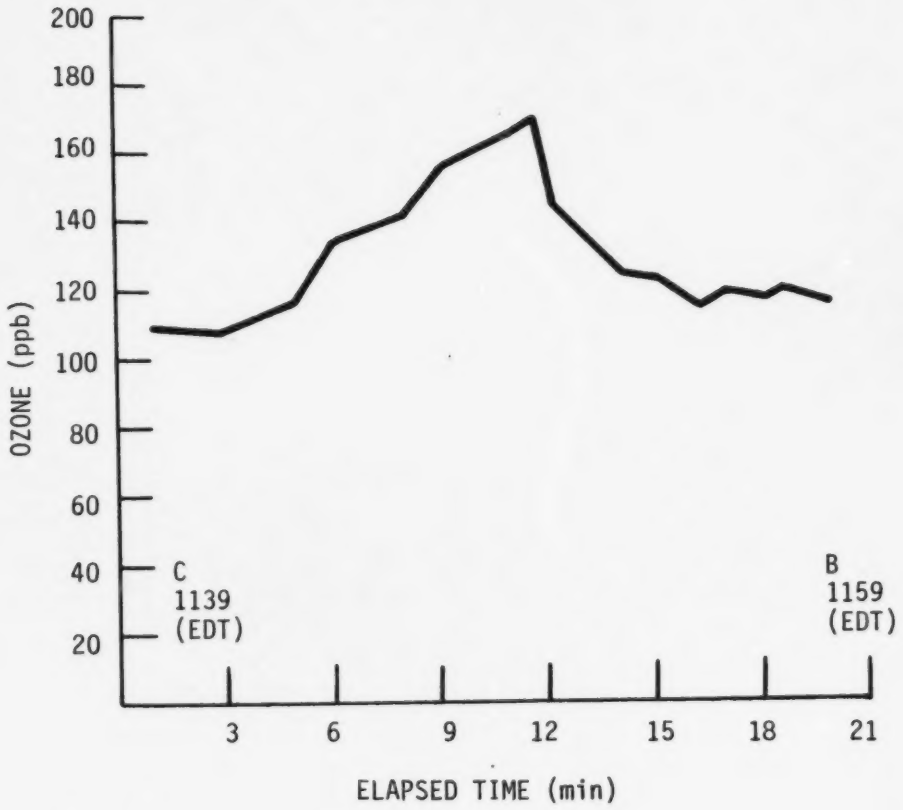

Figure B-2. Crossplume ozone profile recorded 20 km downwind of Baltimore at 1500 ft on July 21, 1980 by WSU aircraft.

WSU flight #1 (1045-1355) - The WSU aircraft monitored pollutant concentrations in the region between 20 and 80 km northeast of Baltimore (Figure B-1). Crosswind traverses were flown 1500' above ground level at distances of 20, 60 and 80 km downwind of the city. At 20 km, ozone concentrations were less than 110 ppb at the most southerly end of the traverse. As shown in Figure B-2, a broad ozone plume was evident in the central region of the traverse with maximum ozone concentrations in excess of 160 ppb. Ozone levels to the north of the plume returned to the 110-115 ppb range. Further to the east at a distance of 60 km, an ozone plume similar in shape and concentration to that recorded at 20 km was observed (see Figure B-2). The highest ozone concentrations (~165 ppb) blanketed the region from Havre De Grace south to Crystal Beach. At the southern end of the traverse ozone levels were about 80 ppb. The traverse at 80 km provided a similar ozone pattern as observed at 20 and 60 km. Ozone concentrations were highest in the northern section of the traverse with a definite ozone bulge in the region east of Havre De Grace. As observed in the earlier traverses, maximum ozone levels were 160-165 ppb. Higher ozone concentrations were recorded on the inbound flight leg to Martin Airport. In the region between Havre De Grace and the airport, O_3 concentrations increased from 160 ppb to well over 200 ppb. Peak concentrations of about 250 ppb were recorded at 1500' in the vicinity of Rock Hall near the eastern shore of Chesapeake Bay.

WSU flight #2 (1700-1900) - Ozone concentrations above 200 ppb were recorded over much of the region northeast of Baltimore during this late afternoon flight. The three crosswind traverses (Figure B-3) at 20, 60 and 80 km downwind of Baltimore exhibited similar ozone profiles. Figure B-4 shows ozone concentrations recorded along the 60 km tranverse. Concentrations

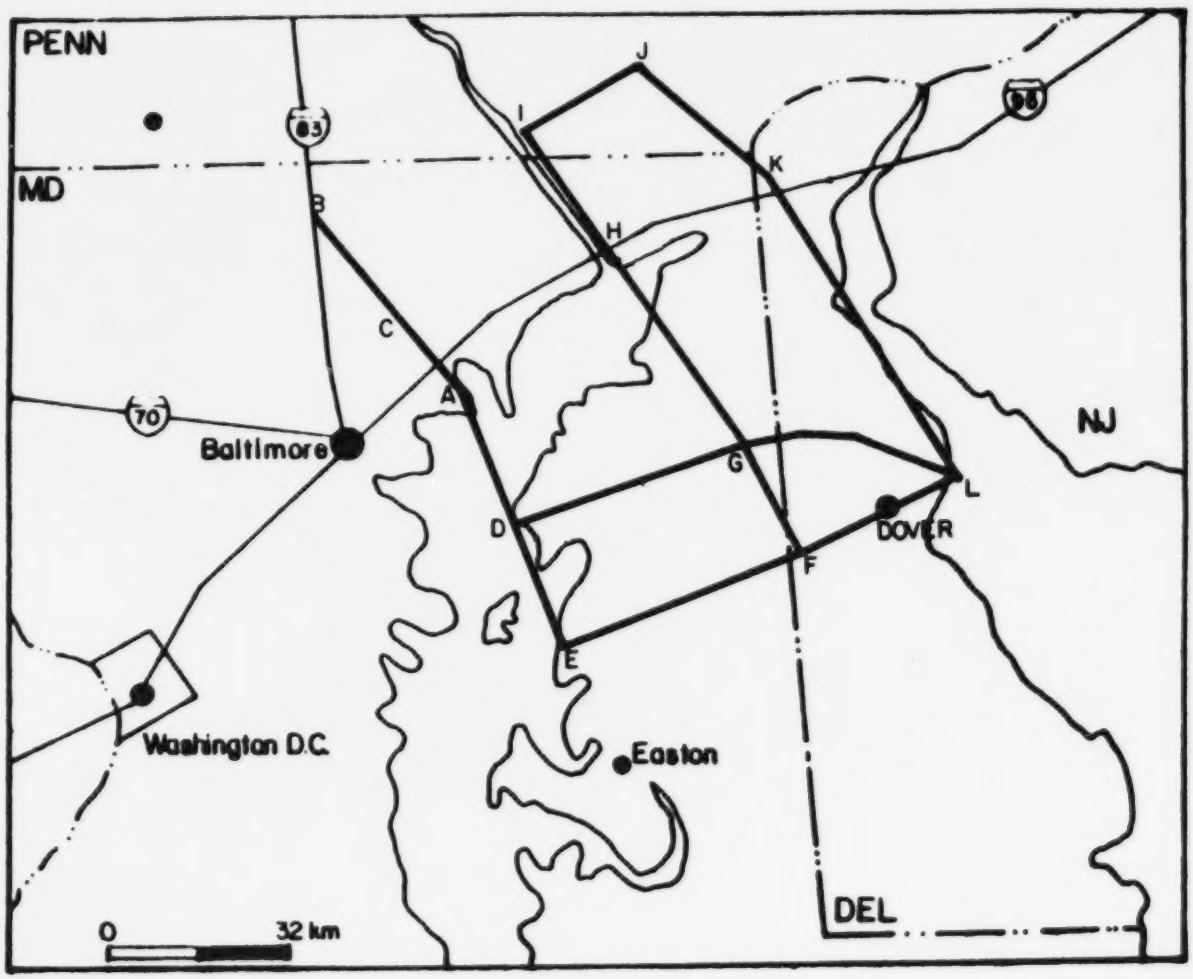

Figure B-3. July 21 afternoon flight path.

WSU #2

Leg	Altitude	Time
A-B	1500	1703-1710
B-E	1500	1711-1737
F-I	1500	1745-1808
J-L	1500	1815-1836
L-A	1500	1837-1908

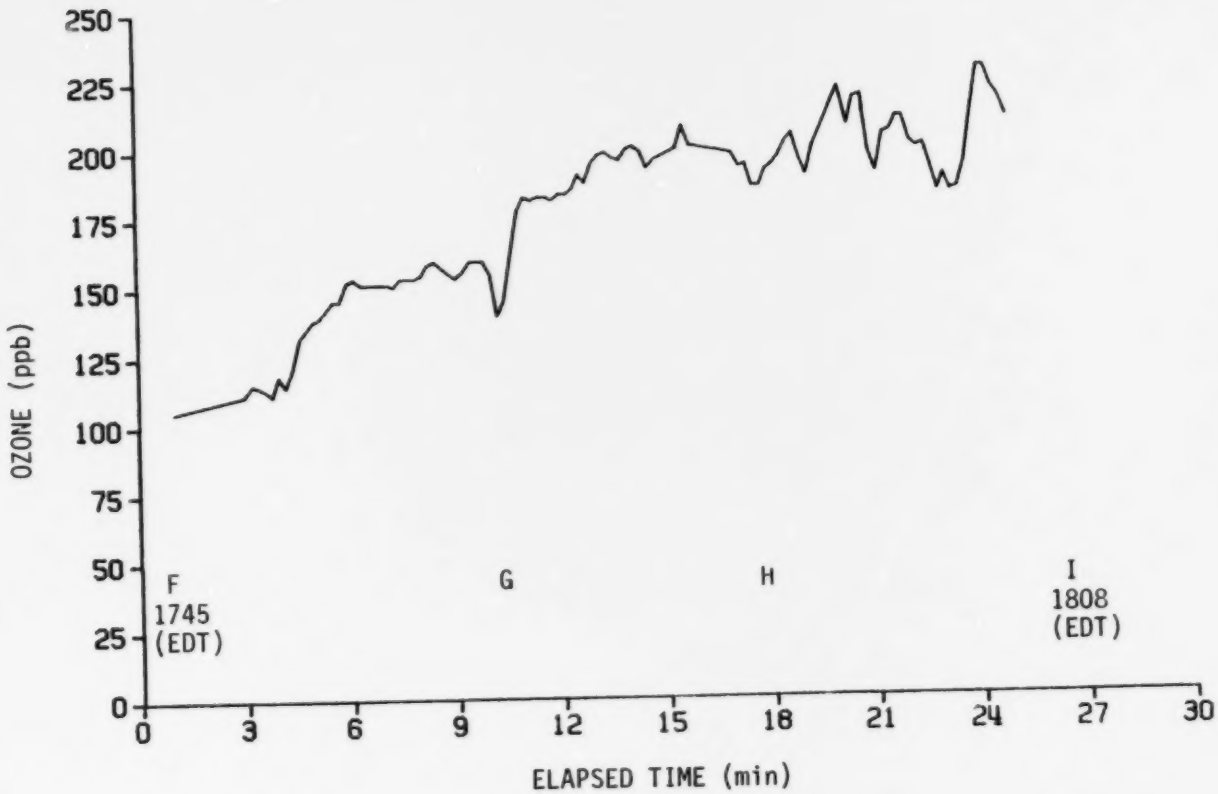

Figure B-4. Crossplume ozone profile recorded 60 km downwind of Baltimore at 1500 ft on July 21, 1980 by WSU aircraft.

were in the 100-110 ppb range in the southern portion. As the aircraft proceeded in a northerly direction, ozone concentrations increased in a systematic fashion to about 225 ppb at the northern extremity of the flight leg. It is obvious from these data that the flight route should have extended further to the north in order to transect the entire width of the Baltimore-Washington plume.

APPENDIX C

Data Summary and Analysis

July 25, 1980

On July 25 a high pressure center was positioned directly over the Baltimore-Washington area. Clear skies with scattered cumulus clouds were observed during the day (8). The mixing level was below 700' prior to 0900 and then increased rapidly throughout the late morning hours to a level of ~6500' by early afternoon (9). The computed trajectory for an air parcel leaving Washington, DC at 0800 is shown in Figure C-1. The trajectory passes over Baltimore at 1300 and then follows a more westerly course reaching the Delaware border at 1800.

Three flights were conducted between the hours of 0900-1900 EDT (Figures C-2 and C-3). The WSU aircraft surveyed the region from 20 km upwind to approximately 60 km downwind of Baltimore during the 0900-1230 period. Pollutant levels in the region from 20 km upwind to 60 km downwind of Baltimore were monitored with the BNL aircraft between 1200 and 1530. During the late afternoon hours (1530-1900), the WSU aircraft monitored pollutant buildup in the region downwind of Baltimore. All three of these flights consisted of vertical soundings plus several traverses perpendicular to the wind direction.

WSU flight #1 (0900-1230) - Ozone concentrations varied from 50-60 ppb in the altitude range between 1500' and 3000'. At 8000' ozone had decreased to approximately 30 ppb. Upwind of Baltimore ozone concentrations were about 60 ppb in the layer between 1500 and 4000'. Ozone and NO_x were elevated at all traverse points downwind of Baltimore. North-South traverses over Martin airport at 1500, 3000 and 4500' showed maximum ozone levels of 80 ppb which corresponds to about a 20 ppb buildup in the Baltimore plume. NO_x concentrations in the plume were as high as 100 ppb. Total non-methane hydrocarbon levels recorded in the plume at 1500, 3000 and 4500' were 300 ppbC, 289 ppbC and 222 ppbC, respectively. This is considerately higher

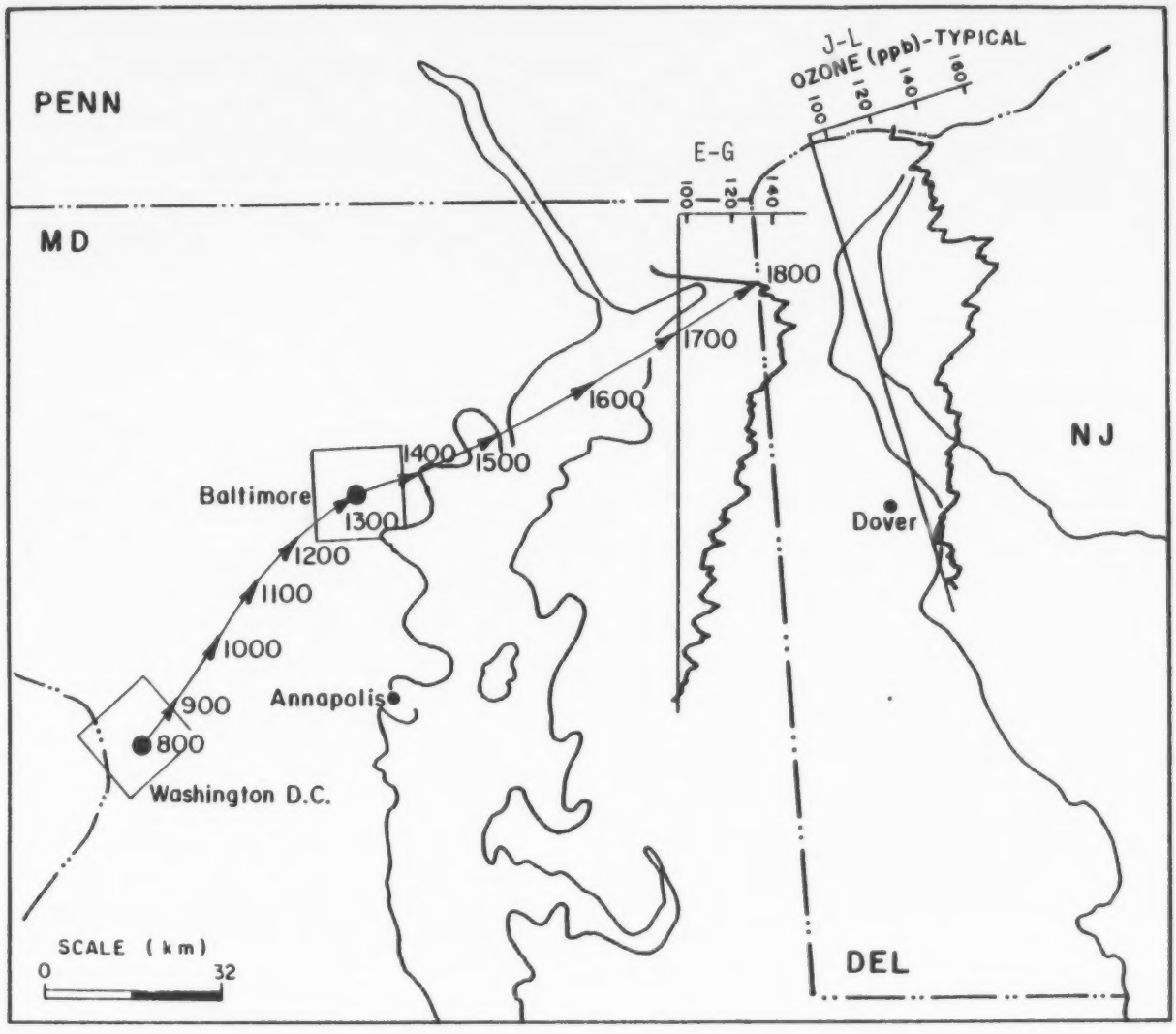

Figure C-1. Air mass trajectory and ozone crossplume profiles (EG - 1000', 1637-1700; JL - 3000', 1824-1839) on July 25, 1980.

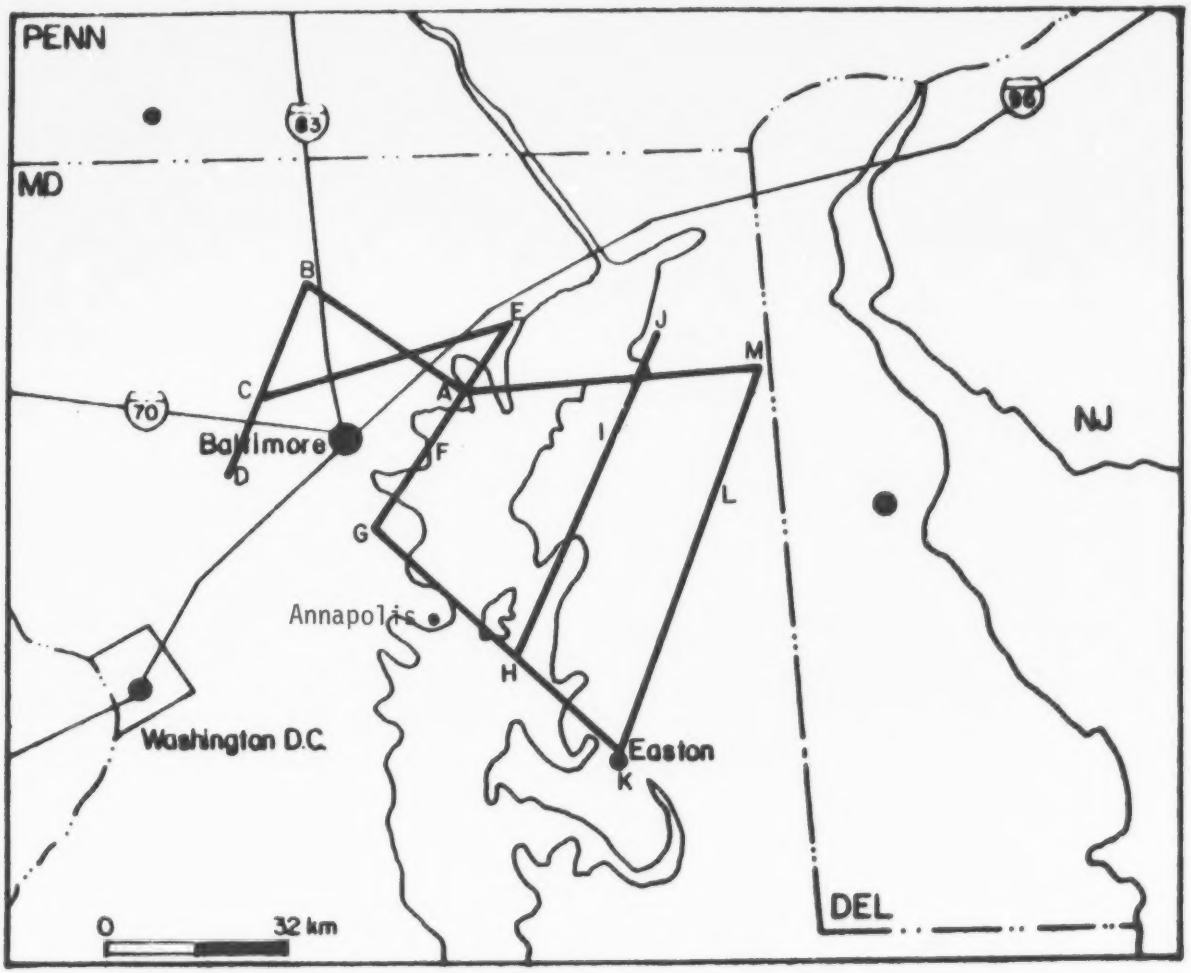

Figure C-2. July 25 morning flight path.

WSU #1

Leg	Altitude	Time
A-B-C-D	1500	0900-0919
D-C-E	3000	0952-1010
E-G	1500	1011-1050
G-E	3000	1051-1103
E-G	4500	1104-1116
H-J	3000	1120-1138
J-H	1500	1139-1153
K-M	1500	1157-1213
M-A	1500	1213-1223

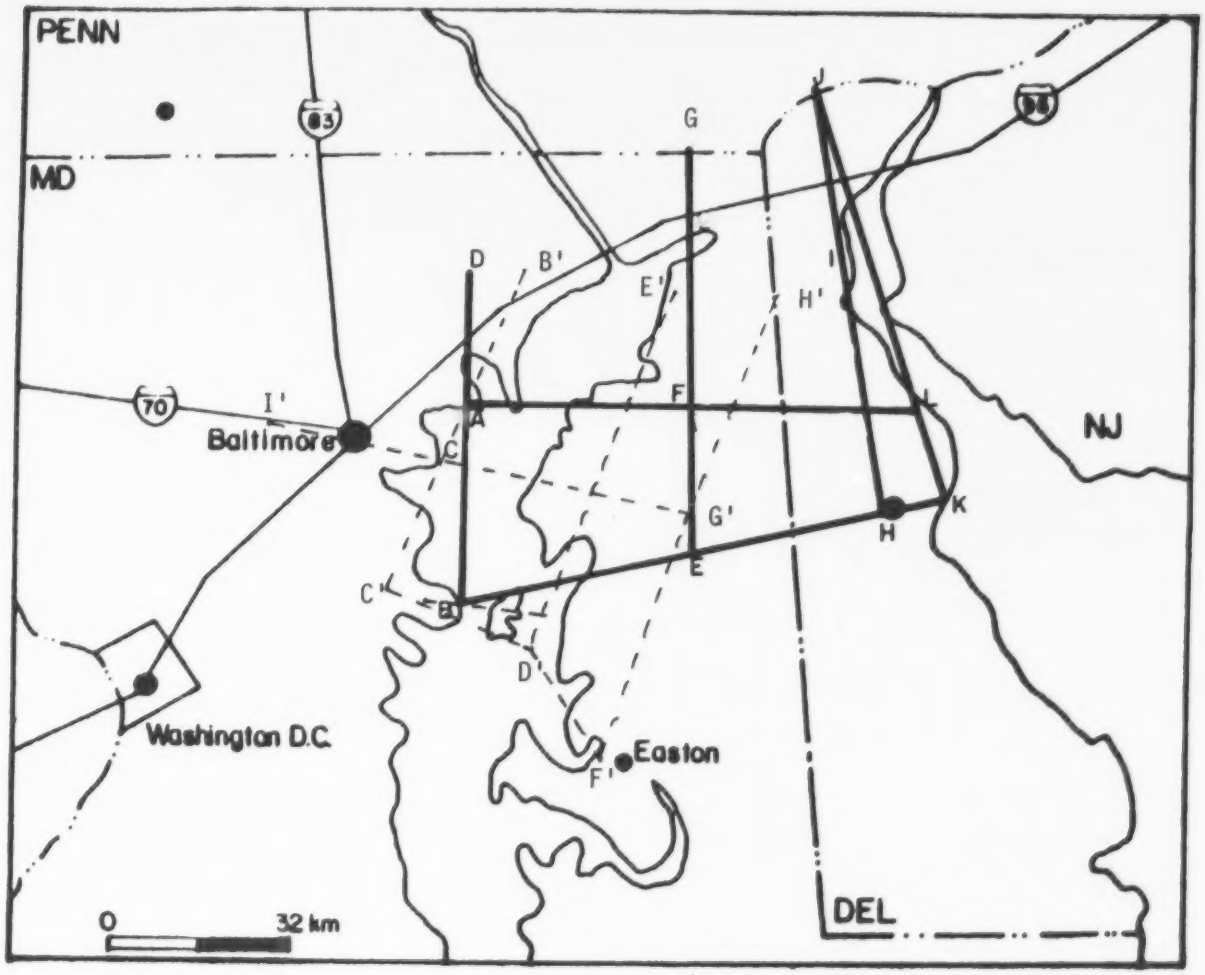

Figure C-3. July 25 afternoon flight paths.

BNL #1 (dashed line)

Leg	Altitude	Time
B'-C'	1500	1235-1252
C'-B'	2800	1256-1311
B'-C'	3800	1314-1329
D'-E'	3000	1339-1357
E'-D'	1500	1359-1422
F'-H'	1500	1430-1450
H'-G'	3000	1454-1506
G'-I'	1500	1508-1536

WSU #2 (solid line)

Leg	Altitude	Time
A-B	4500	1555-1603
B-D	3000	1604-1615
D-B	1000	1616-1626
E-G	1000	1637-1700
G-E	3000	1701-1721
H-J	3000	1726-1742
J-H	1000	1743-1800
K-J	1000	1803-1823
J-L	3000	1824-1839
L-A	1000	1840-1901

than the 18 ppbC concentration observed in a sample collected at 1500' 20 km upwind of Baltimore. Ground level hydrocarbon concentrations on the eastern edge of Baltimore averaged approximately 1000 ppbC during the 0600-0900 period on July 25.

Plume traverses 45 km downwind showed little evidence of pollutant buildup at 3000'; however, significant ozone production was observed at 1500'. Ozone exceeded 100 ppb in the vicinity of the Bay Bridge northeast of Annapolis. Further downwind at 65 km, there was some evidence of a pollutant plume with maximum ozone concentrations of 90 ppb observed.

BNL flight #1 (1200-1530) - A vertical profile at 1210 showed a definite temperature inversion at 6500'. This clearly marked the top of the mixing layer as pollutant levels dropped significantly above that point. Ozone concentrations decreased gradually from 50 ppb to 40 ppb in the 1000 to 5000 ft region and fell below 30 ppb above the mixing layer.

Plume traverses during the midday flight were made over and downwind of Baltimore at the same locations as those made during the morning flight. North-south passes in the vicinity of Martin airport showed that ozone levels had increased to about 100 ppb at 1500' and 3000' but generally remained below 80 ppb at 4500'. Along the 45 km downwind traverse maximum inplume ozone concentrations approached 110 ppb at 1500'. The downwind traverse at 65 km showed maximum ozone concentrations of about 95 ppb.

WSU flight #2 (1530-1900) - The same general type of pattern was flown during the afternoon hours on July 25. However, the region surveyed was extended somewhat and shifted northward.

North-south traverses in the vicinity of Martin airport showed highest ozone levels of about 160 ppb directly downwind of Baltimore. Figure C-4

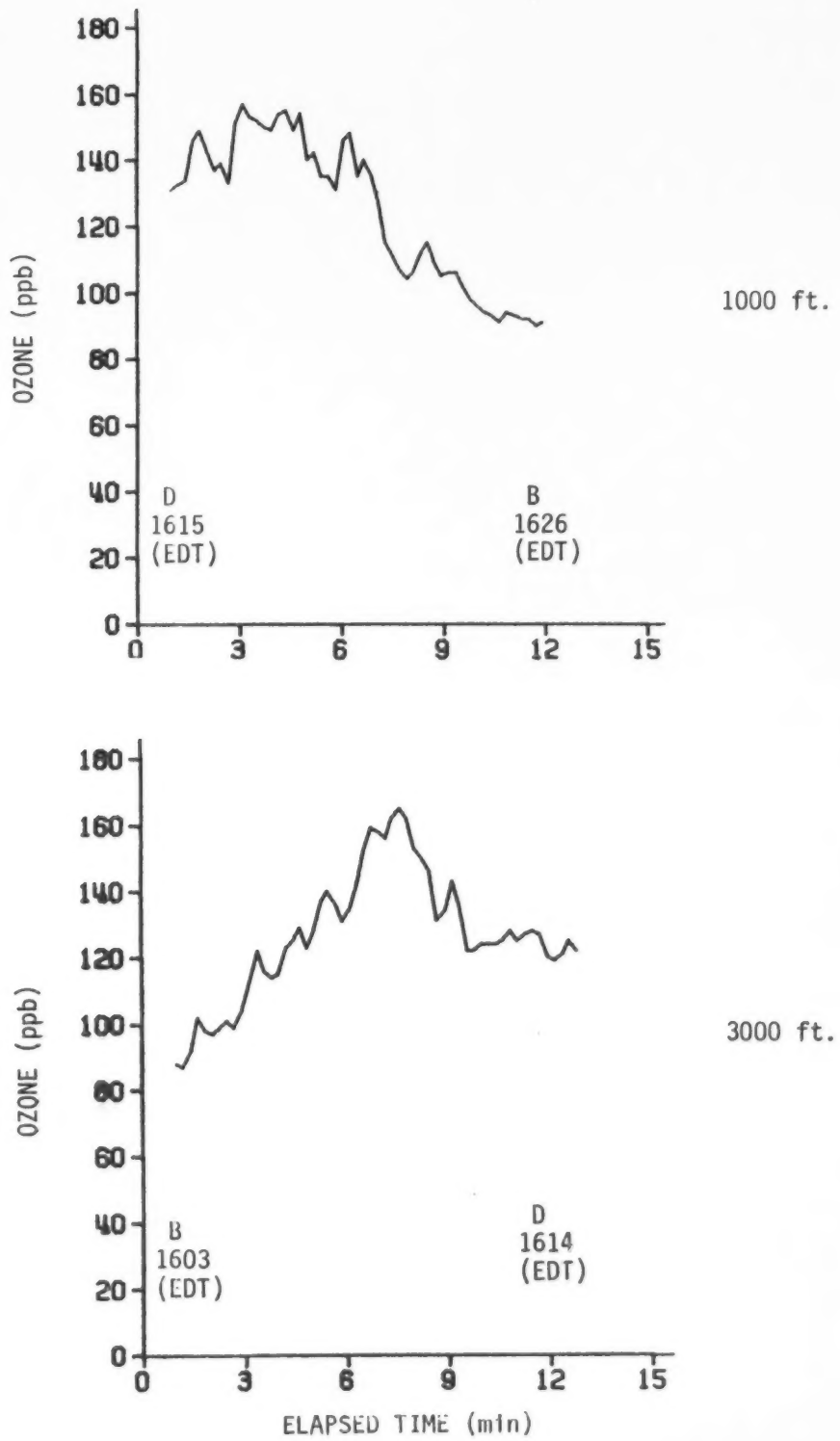

Figure C-4. Crossplume ozone profiles recorded 20 km downwind of Baltimore at 1000 ft and 3000 ft on July 25, 1980 by WSU aircraft.

shows plots of ozone concentration between points B and D (Figure C-3) at altitudes of 1000' and 3000'. Crosswind traverses approximately 60 km downwind of Baltimore showed maximum ozone levels of 150 ppb at 1000' and about 160 ppb at 3000'. Plume shape at both of these altitudes implies an interaction between the Baltimore and Washington, DC plumes. As shown in Figure C-5, at 1000' there is a constant increase in O_3 from the southern most point of the traverse until the aircraft exits the plume. O_3 concentrations to the north of the Baltimore plume were about 80 ppb. At 3000', the cross-sectional ozone profile indicates the presence of two plumes (Figure C-6). Still further downwind at (~90 km) ozone levels were elevated toward the northern edge of the traverse with a gradual decrease from ~150 ppb to 100 ppb going from north to south.

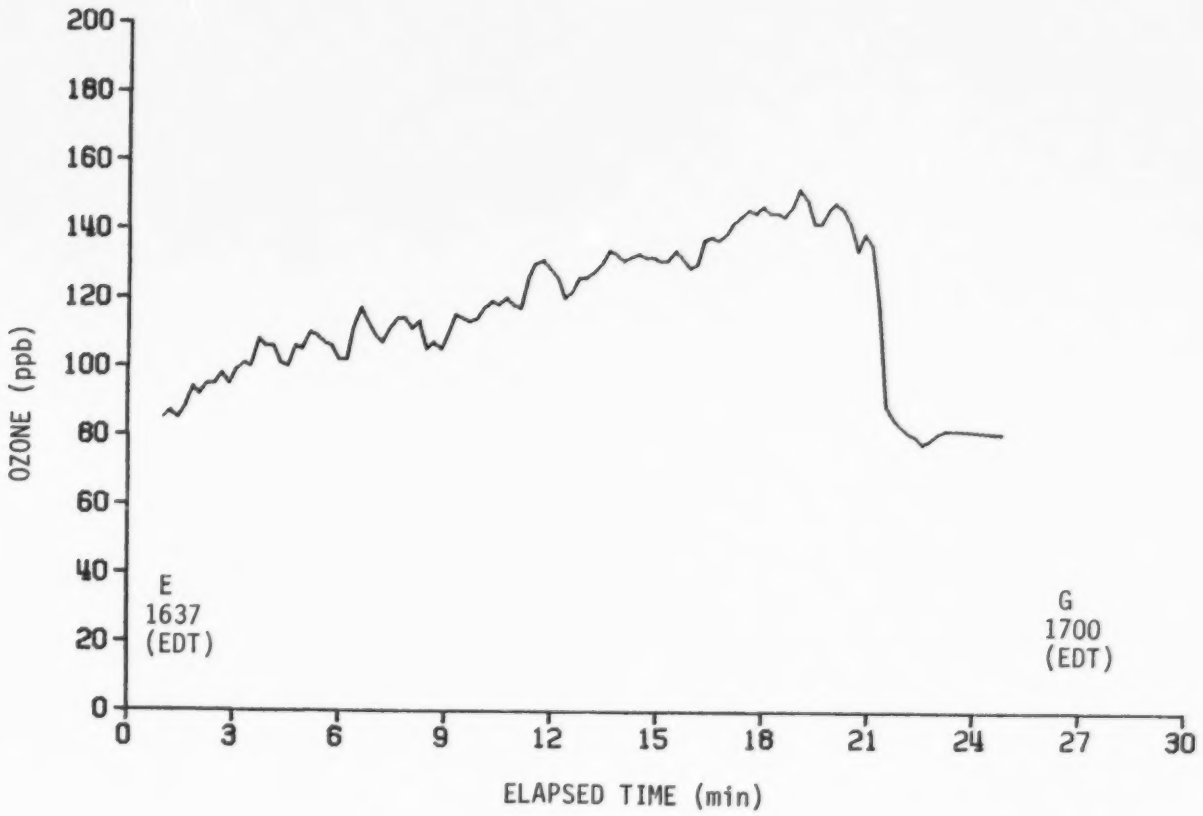

Figure C-5. Crossplume ozone profile recorded 60 km downwind of Baltimore at 1000 ft on July 25, 1980 by WSU aircraft.

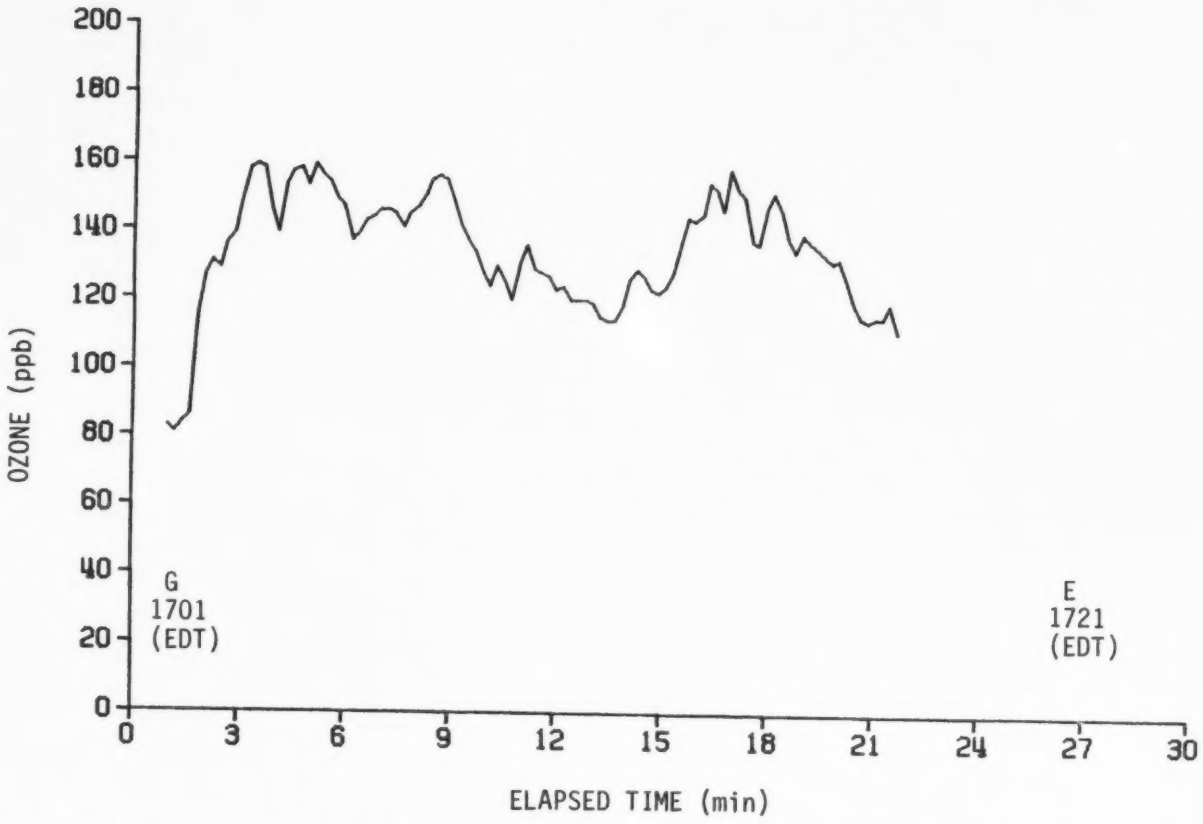

Figure C-6. Crossplume ozone profile recorded 60 km downwind of Baltimore at 3000 ft on July 25, 1980 by WSU aircraft.

APPENDIX D

Data Summary and Analysis

August 2, 1980

The wind flow on August 2 shifted from northwesterly in the morning to southwesterly in the afternoon hours. A scattered to broken alto-cumulus cloud cover was present in the afternoon. There was some thunderstorm activity in the Baltimore area late in the day as temperatures reached the high nineties (8). The mixing level increased from the surface at 0700 to about 2000' at 1000 and reached a maximum of about 4500' during the afternoon hours (9).

Four aircraft flight missions were flown between the hours of 0846 and 2141 EDT on August 2 (Figures D-1 and D-2). During these flights, the region from about 20 km upwind to 120 km downwind of Baltimore was surveyed.

BNL flight #1 (0843-1226) - Ozone levels upwind of Baltimore at 1500' averaged 65 ppb. The O_3 concentration increased to about 75 ppb at 2000' and then decreased gradually with altitude to the 40 ppb range at 5000'. The vertical temperature profile recorded during an aircraft sounding at 0915 shows an inversion layer at approximately 2000' (Figure D-3). There was no evidence of an ozone plume emanating from either Washington, DC or Baltimore during a traverse approximately 40 km downwind of the two cities. Crosswind transects were flown at 1500', 3000' and 4500'. Enhanced NO_x levels were recorded southeast of Baltimore on the 1500' pass. A long crosswind traverse which encompassed the region from southeast of WDC to northeast of Baltimore revealed a small ozone bulge downwind of Baltimore at 60 km. Ozone concentrations between the two cities and downwind of WDC were less than 80 ppb while those to the east of Baltimore rose to about 90 ppb.

WSU flight #1 (1233-1620) - The flight route consisted of several crosswind traverses at distances of 25, 40, 60 and 80 km downwind of the Baltimore-Washington, DC urban complex. On the 25 km pass at 1500', an ozone plume

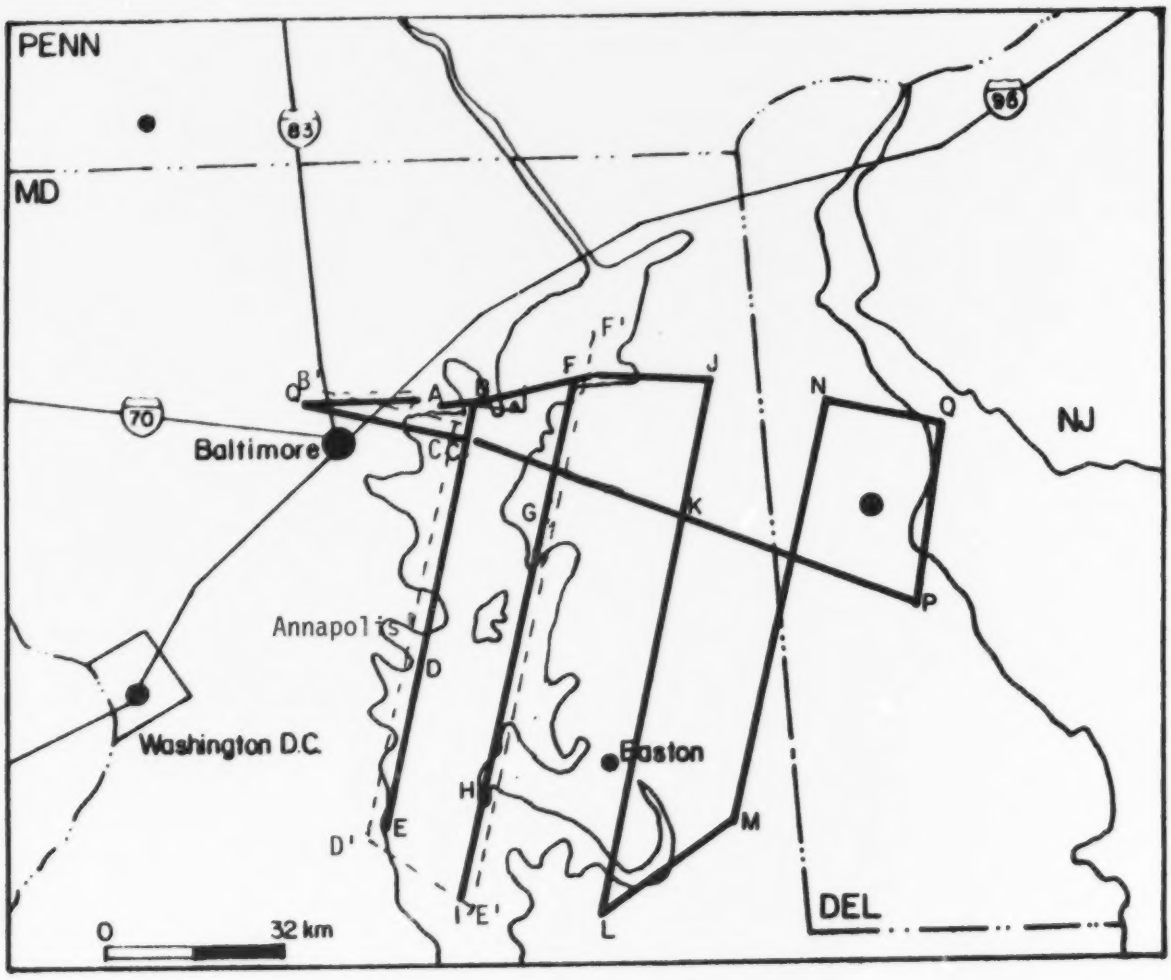

Figure D-1. August 2 morning and early afternoon flight paths.

BNL #1 (dashed line)

Leg	Altitude	Time
A-B'	1500	0846-0907
B'-C'	5800	0932-0945
C'-D'	4500	0949-1015
D'-C'	3000	1017-1045
C'-D'	1500	1047-1115
E'-F'	1500	1124-1200

WSU #1 (solid line)

Leg	Altitude	Time
B-E	1500	1236-1300
E-B	3000	1301-1322
F-G	6000	1331-1338
G-I	1500	1346-1403
I-F	3000	1404-1427
J-L	1500	1432-1456
M-N	1500	1504-1523
O-P	1500	1529-1539
P-Q	1500	1539-1608

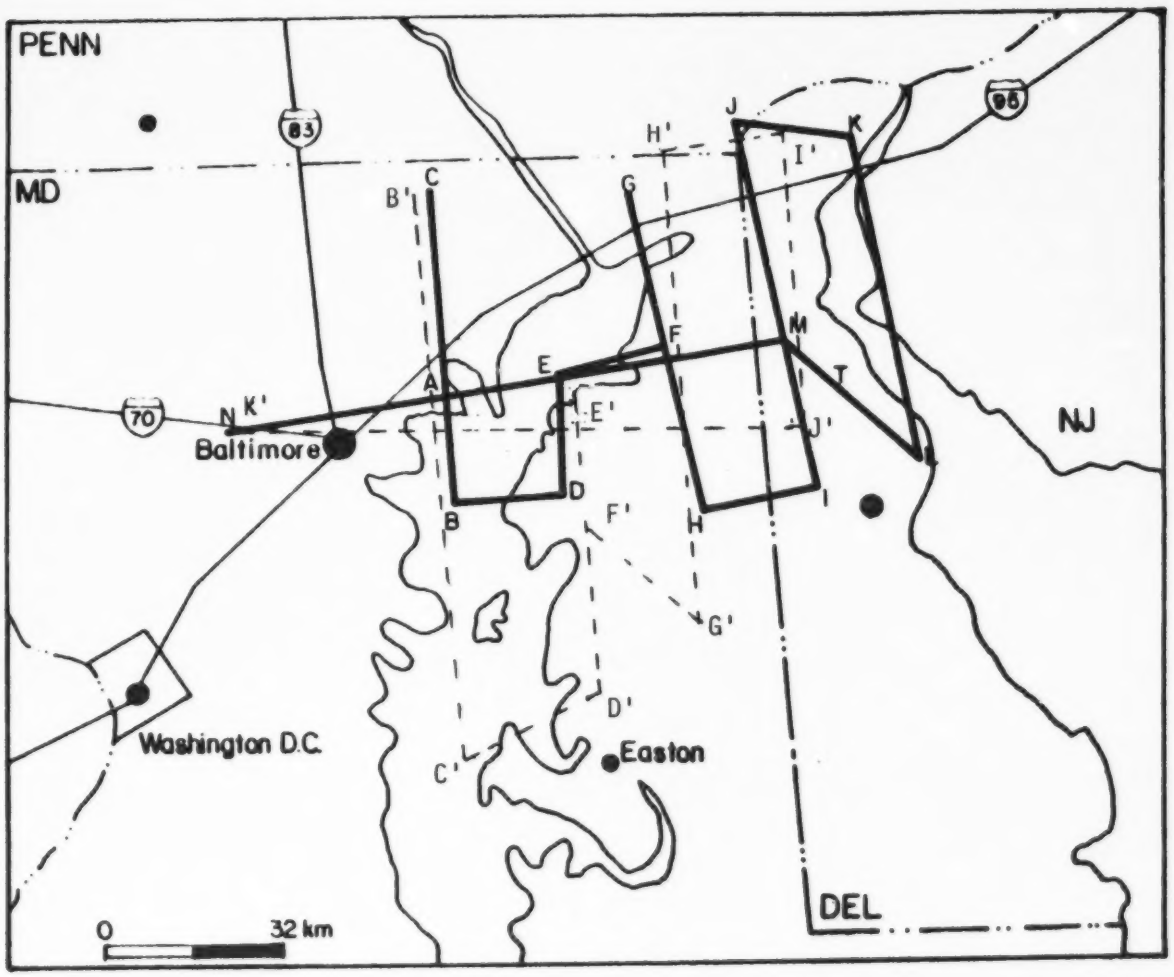

Figure D-2. August 2 late afternoon flight paths.

BNL #2 (dashed line)			WSU #2 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B'	2800	1640-1649	A-B	4500	1854-1900
B'-C'	1500	1653-1724	B-C	3000	1901-1914
D'-E'	1500	1734-1745	C-B	1500	1915-1931
E'-F'	2800	1748-1756	D-E	1500	1935-1939
G'-H'	1500	1805-1826	F-G	3000	2006-2014
I'-J'	1500	1834-1856	G-H	1500	2015-2030
J'-K'	1500	1856-1922	I-J	1500	2033-2045
			K-L	1500	2051-2105
			M-N	1500	2113-2141

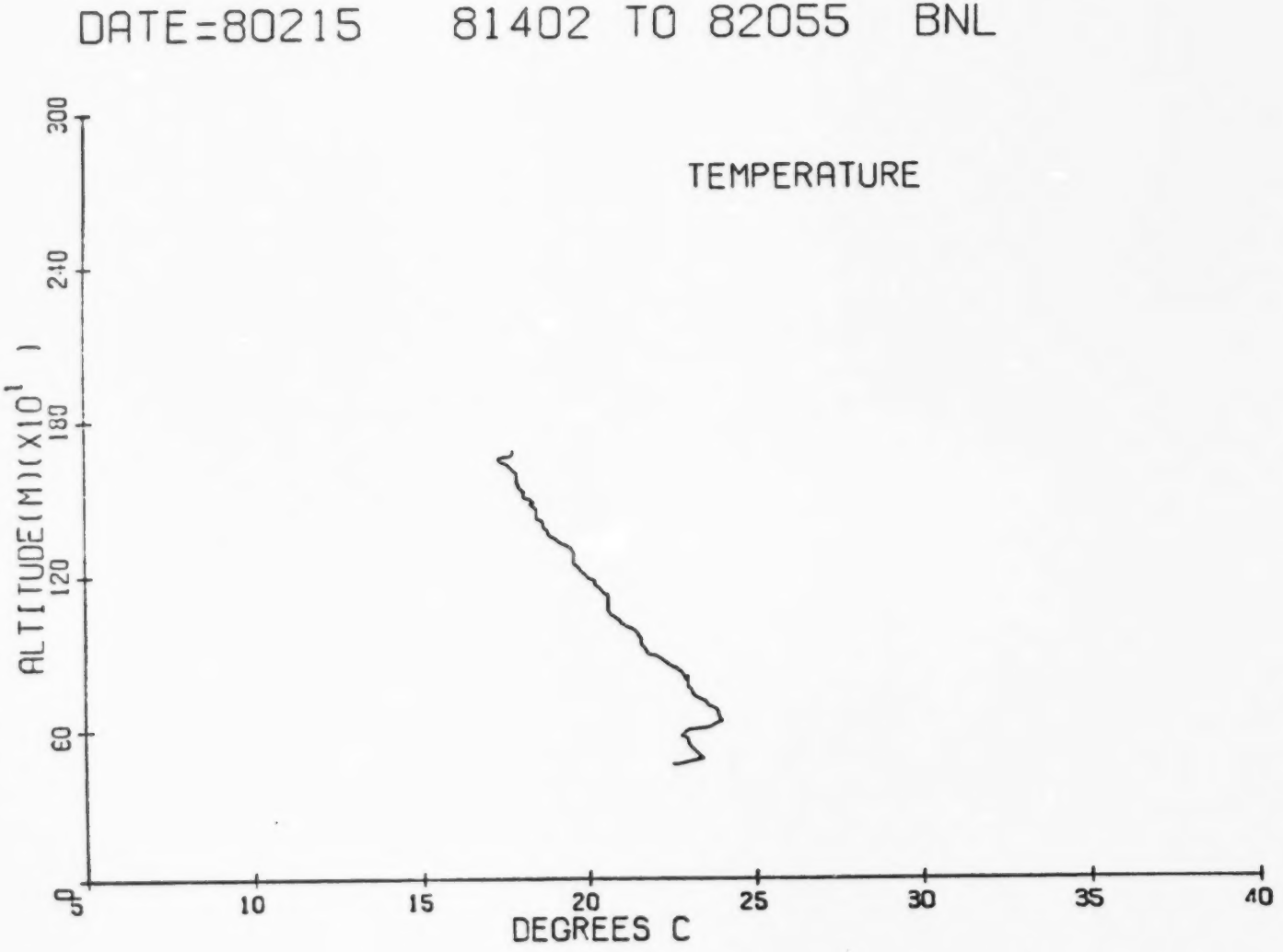

Figure D-3. Vertical temperature profile recorded by the BNL aircraft on the morning of August 2, 1980.

was clearly evident. Beginning at the northern end of the traverse, O_3 concentrations increased from about 100 ppb to a peak of 155 ppb approximately midway between Baltimore and Washington. The O_3 concentrations at the extreme southern end of the traverse were once again about 100 ppb. At a distance of 40 km from Baltimore, a traverse at 3000' showed elevated ozone levels extending from directly east of Annapolis to the northern end of the traverse. The peak ozone concentration along this path was approximately 140 ppb. Elevated ozone concentrations were recorded along the entire 60 km downwind traverse at an altitude of 1500'. A peak value of 150 ppb was measured directly east of Baltimore. Farther to the east at 80 km from Baltimore, a broad band of elevated ozone was observed in the northern half of the aircraft traverse. Peak concentrations were about 140 ppb at 1500'. Highest ozone readings (~165 ppb) on this flight were observed in the region 40 to 60 km southeast of Baltimore during the return trip to the airport.

BNL flight #2 (1555-1931) - During this flight crosswind traverses were made to the east of Baltimore and Washington, DC at distances of 20, 40, 60 and 80 km. Elevated oxidant levels were observed at all distances when flying at 1500'. Peak concentrations of about 120 ppb were recorded in the region between 40 and 60 km east of the two cities. Individual plumes emanating from Baltimore and Washington were not clearly discernable. Instead, a broad region of elevated ozone concentration was observed along each crosswind traverse which roughly corresponded to the distance between the two urban centers (50-70 km).

WSU flight #2 (1837-2151) - The WSU aircraft monitored the region downwind of Baltimore and Washington using a flight pattern similar to that employed in BNL flight #2. Ozone levels 20 km downwind of Baltimore were elevated at

1500'. Peak inplume values were approximately 140 ppb compared to background levels of 100 ppb. At points further downwind, it is difficult to clearly define oxidant plume boundaries. It appears that boundary layer stratification had begun to occur with the result being vertical layers of differing ozone concentration. For example, a vertical sounding 40 km downwind of Baltimore showed ozone levels less than 100 ppb below 1000', concentrations approaching 130 ppb in a narrow band between 1500 and 2000', and lower values again at the higher altitudes. Since most of the downwind traverses were flown at 1500', it is difficult to tell whether recorded ozone bulges represent plumes or simply a breakthrough into the higher concentration ozone band aloft.

APPENDIX E

Data Summary and Analysis

August 3, 1980

Winds were from the southwesterly direction during the afternoon hours on August 3. Thunderstorms developed during the late afternoon hours, otherwise conditions were generally favorable for the production of photochemical oxidants. The noon mixing height was about 3500'. An aircraft vertical profile 20 km upwind of Baltimore at 1230 showed a weak temperature inversion beginning at about 3500' and extending up to 5000'. A rapid decrease in ozone concentration with altitude coincided with the lower boundary of this temperature break. These data are plotted in Figure E-1. Integrating nephelometer measurements exhibited a light scattering pattern that paralleled the vertical ozone profile. The B_{scat} values were 2.4×10^{-4}/m with little variation up to 3500'. A decrease in the haze reading to 0.6×10^{-4}/m occurred in the 3500-5000' region followed by an increase in B_{scat} to 2.0×10^{-4}/m at 6000' and then a gradual decrease to about 0.3×10^{-4}/m at 10,000'. Thus, both light scattering and ozone measurements upwind of Baltimore indicate a polluted surface layer up to about 3500'. This was topped by a relatively clean layer between 4500' and 5500'. Pollutant levels increased again in the 6000-7000' region and then decreased to the lowest levels measured at 11,000'.

Two flights were conducted during the afternoon hours (1211-1733) on August 3 (Figure E-2). The WSU and BNL aircrafts each made several traverses at varying distances downwind of Baltimore and Washington, DC.

WSU flight (1210-1612) - Aircraft traverses perpendicular to the southwesterly wind direction were made at points approximately 20 km upwind and 20, 40, 60, 80 and 100 km downwind of Baltimore. The flight route, as shown in Figure E-2, was designed to transect both the Baltimore and Washington, DC plumes. The most westerly traverse, B-C, established background pollutant levels upwind of Baltimore. It also provided information concerning ozone

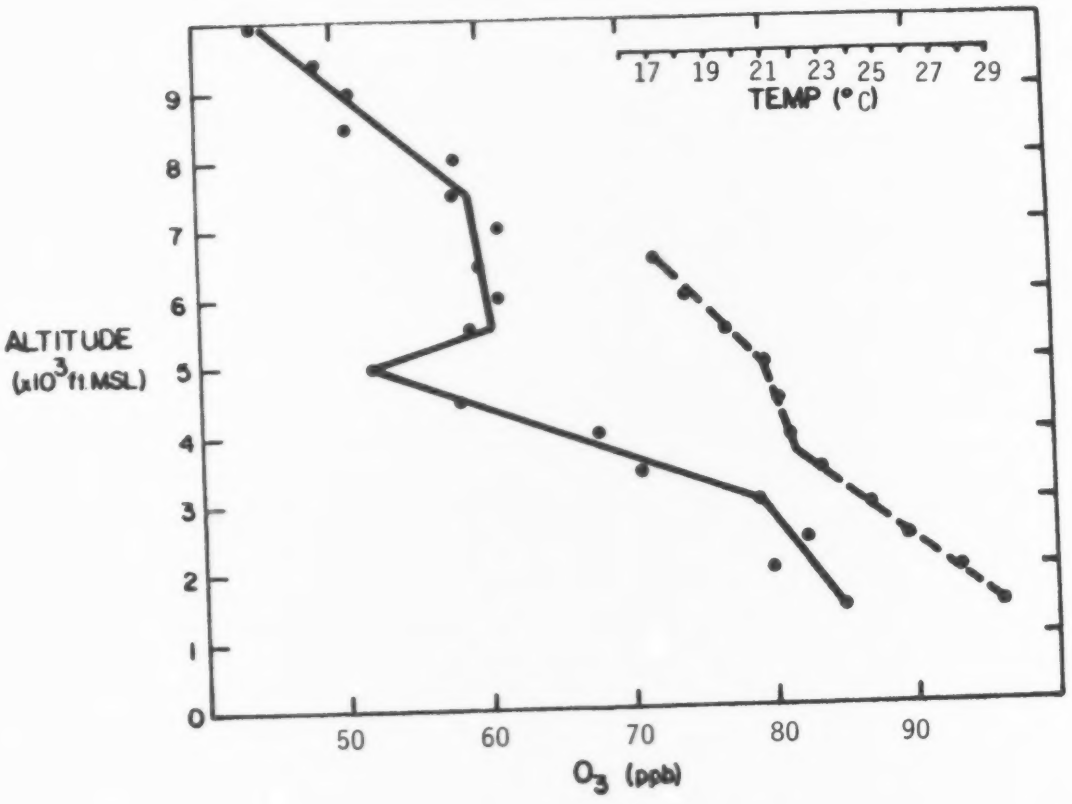

Figure E-1. Ozone and temperature vertical profiles recorded upwind of Baltimore at ~1230 EDT on August 3, 1980 by WSU aircraft.

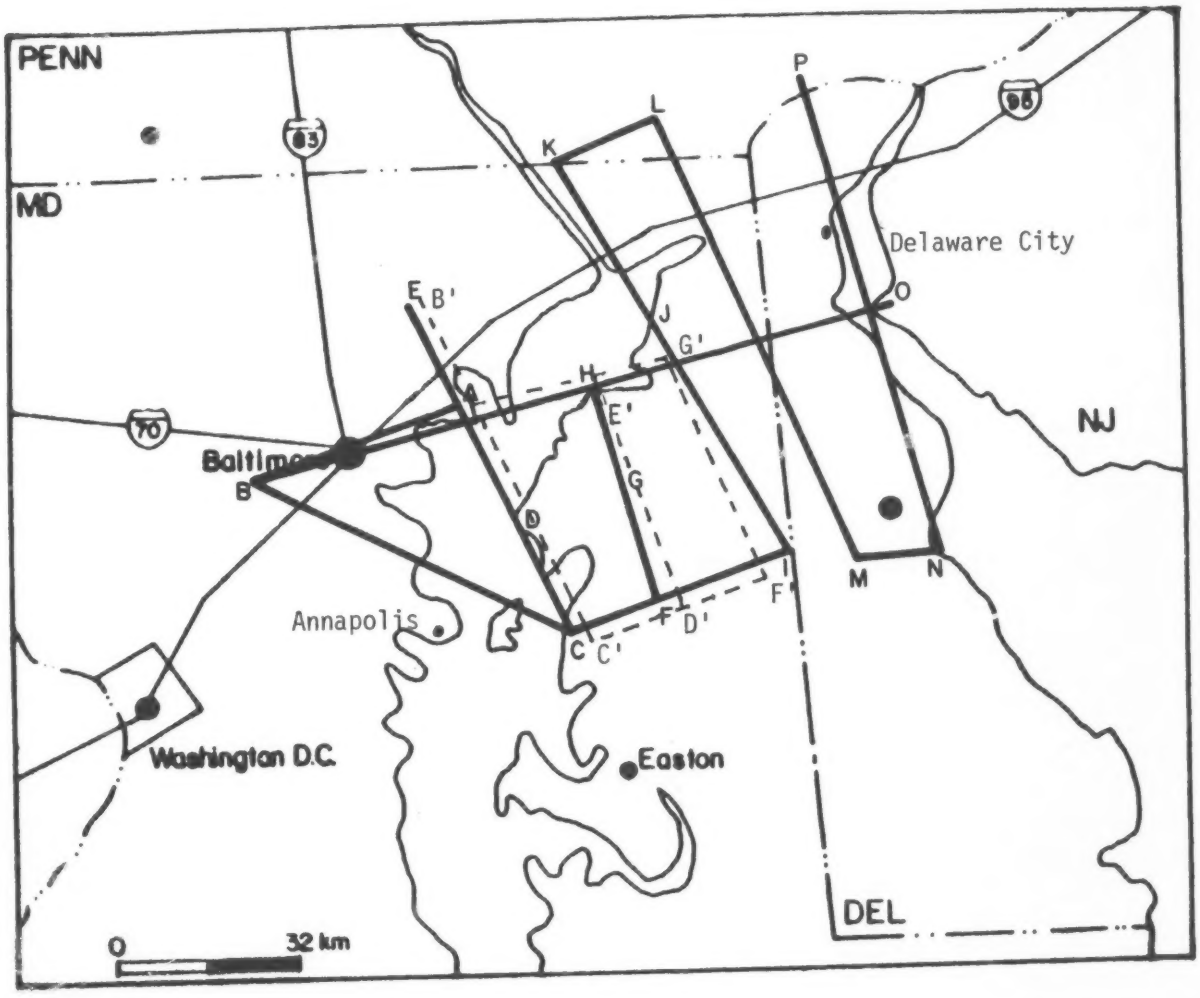

Figure E-2. August 3 flight paths.

WSU (solid line)			BNL (dashed line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B	1500	1211-1224	A-B'	3000	1556-1602
B-C	3500	1255-1310	B'-C'	1500	1605-1627
C-E	3000	1311-1325	D'-E'	1500	1632-1644
E-C	1500	1326-1343	E'-D'	3000	1647-1659
F-H	1500	1346-1357	F'-G'	1500	1703-1716
H-F	3000	1358-1411			
I-K	1500	1415-1436			
L-M	1500	1439-1459			
N-P	1500	1503-1523			
P-O	1500	1523-1531			
O-B	1500	1531-1601			

buildup in the Washington, DC plume about 50 km downwind of the city. As can be seen in Figure E-3, ozone levels at the start and finish of leg B-C were in the 70-80 ppb range. For about the first 4 minutes of the traverse, the aircraft was in the region upwind of Baltimore and not in the Washington, DC plume. Horizontal dimensions of the DC plume were clearly defined by the ozone bulge in the later stages of the aircraft traverse. Ozone levels increased from about 70 ppb outside of the plume to a maximum of 115 ppb in the central portion of the plume which was located to the northeast of Annapolis.

The ozone profile recorded on the 3000' traverse (C to E) immediately downwind of the two urban centers is shown in Figure E-4. The ozone pattern indicates a combined Washington, DC-Baltimore plume encompassing nearly the entire 60 km cross sectional aircraft traverse. Ozone concentrations peaked at about 115 ppb to the east of Baltimore. A return pass across the plume on the same flight track at 1500' showed an ozone profile very similar to that at 3000'.

At traverse points farther downwind, the cross-sectional ozone pattern remained similar to that just described. Figure E-5 shows the ozone profile recorded on traverse L-M (see Figure E-2) 70 km downwind. The northern edge of the plume was clearly marked by an abrupt jump in ozone concentration about 3 minutes into the traverse. The ozone bulge extended for a distance of about 65 km with maximum concentrations in the 120 ppb range. Figure E-6 provides a summary of the ozone pattern observed in the region downwind of Baltimore-Washington, DC on the afternoon of August 3, 1980. The location of the high band of ozone (120-150 ppb) near the middle of the plume was established by a flight leg within the plume boundaries that originated near Delaware City, DE and passed directly over Baltimore to a point about 20 km

Figure E-3. Crossplume ozone profile recorded 20 km upwind of Baltimore at 3500 ft on August 3, 1980 by WSU aircraft.

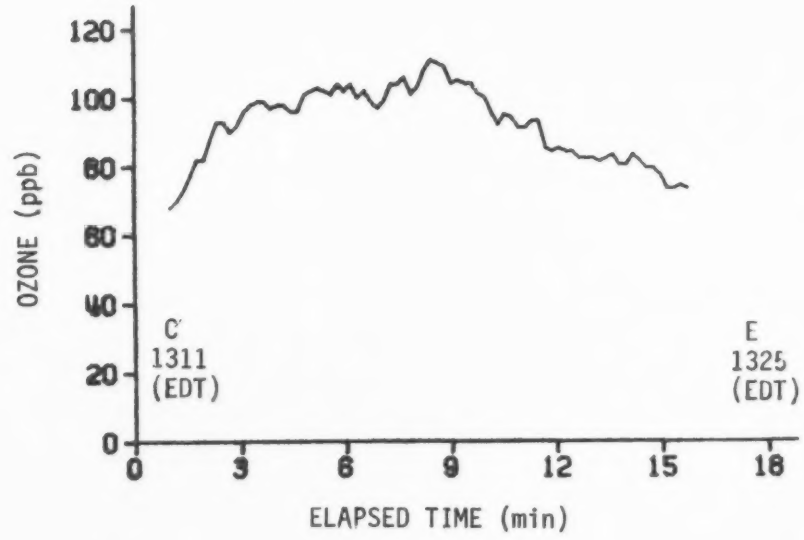

Figure E-4. Crossplume ozone profile recorded 20 km downwind of Baltimore at 3000 ft on August 3, 1980 by WSU aircraft.

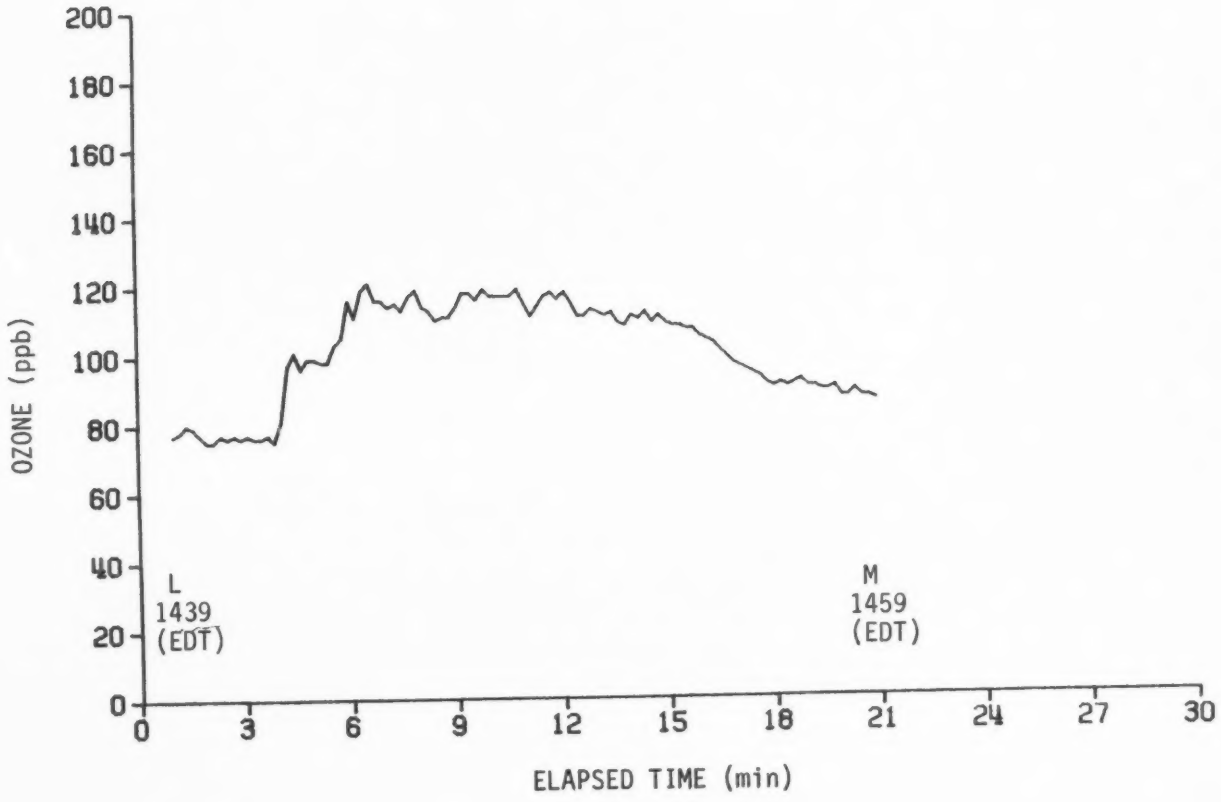

Figure E-5. Crossplume ozone profile recorded 70 km downwind of Baltimore at 1500 ft on August 3, 1980 by WSU aircraft.

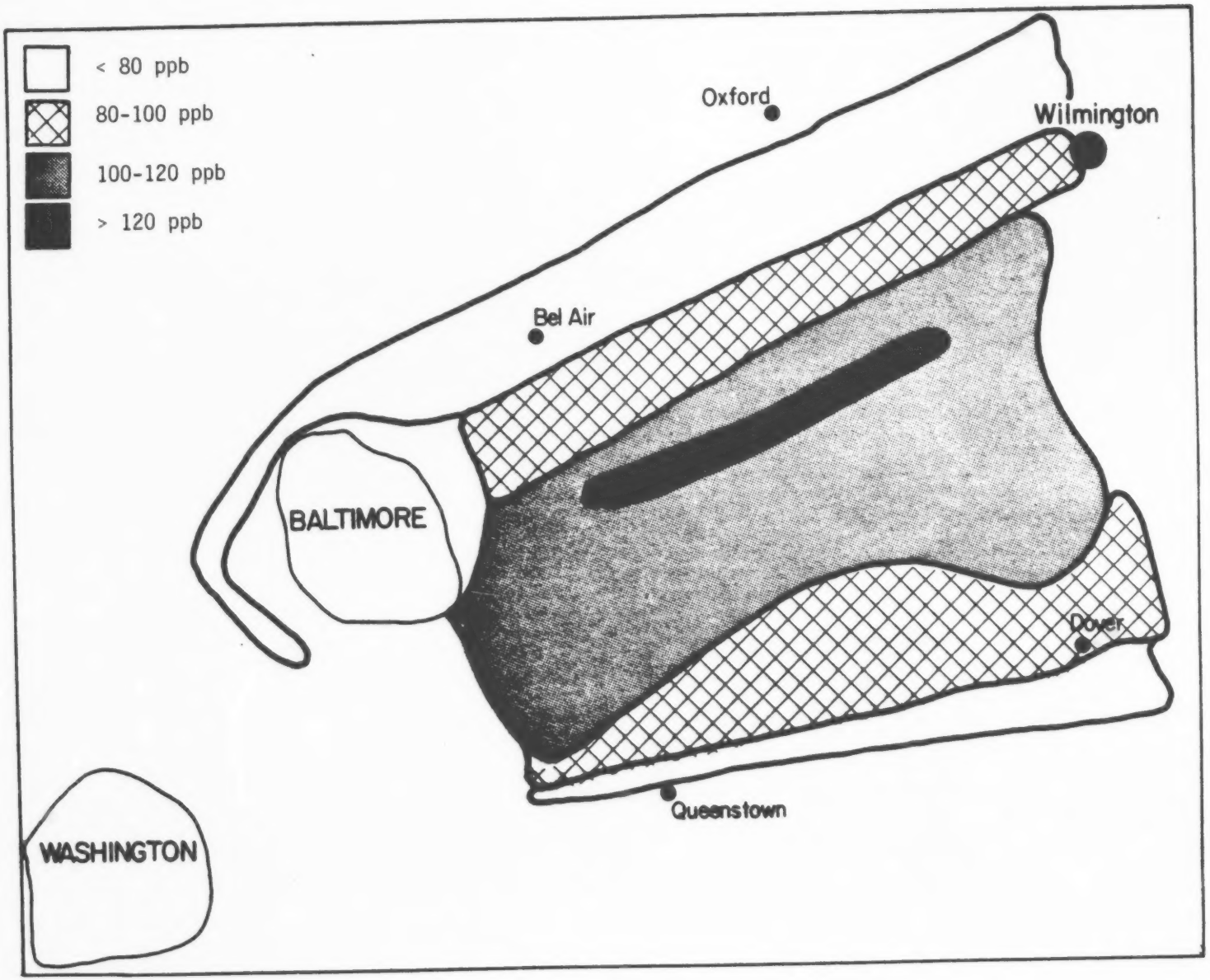

Figure E-6. Ozone levels downwind of Baltimore and Washington, DC on the afternoon of August 3, 1980.

upwind. Figure E-7 shows the changes in ozone concentration recorded along the route. In-plume ozone levels gradually increased from about 110 ppb in the vicinity of Delaware City to a maximum of 150 ppb 30 km to the east of Baltimore. A rather rapid decrease in ambient ozone concentrations was recorded as the aircraft approached and passed over the Baltimore urban area. The upwind ozone concentrations of 80-85 ppb had remained nearly the same as that recorded 4 hours earlier at the beginning of the flight.

BNL flight (1419-1633) - The BNL flight had to be curtailed early due to thunderstorms in the sampling area. Consequently, only one full traverse of the region downwind of Baltimore-Washington, DC was achieved. This traverse followed the same 20 km downwind path as traveled earlier by the WSU aircraft. The ozone profile across the plume was nearly identical to that recorded three hours earlier by the WSU aircraft (see Figure E-4). Maximum ozone concentrations recorded on the BNL traverse at about 1500 were in the 100-150 ppb range where as concentrations as high as 120 ppb had been recorded in the same vicinity about noon. Background ozone levels north of the Baltimore plume remained in the 60-70 ppb range between 1200 and 1500.

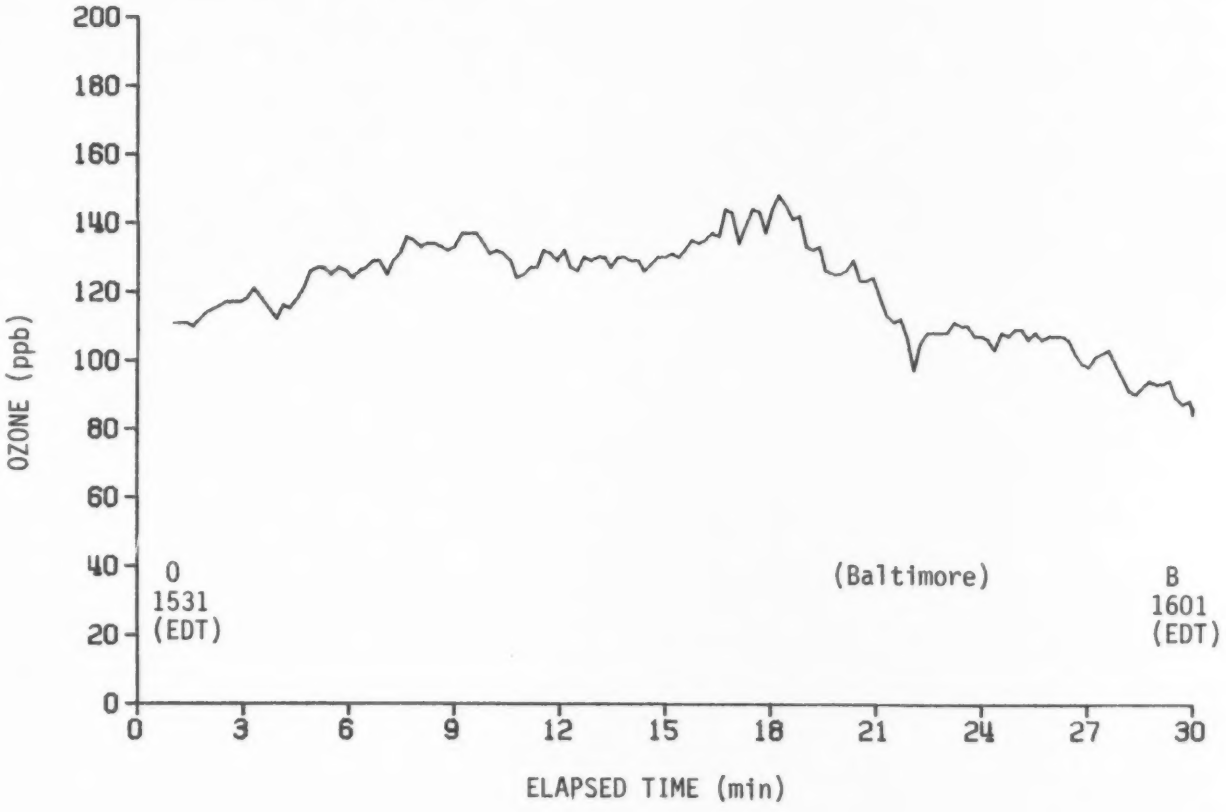

Figure E-7. Ozone concentrations at 1500 ft on August 3, 1980 in region 90 km downwind of Baltimore to 20 km upwind of the city by WSU aircraft.

APPENDIX F

Data Summary and Analysis

August 5, 1980

Thunderstorms developed during the late afternoon hours but throughout most of August 5 conditions were hot, humid and hazy. The mixing level at 0930 was about 1200' as evidenced by elevated NO_x concentrations and depressed ozone levels below that altitude. By mid-afternoon the mixing level had increased to about 4000'. Winds were from the southwesterly quadrant throughout the day.

Three flight missions were flown between the hours of 0830 and 1900 on August 5 (Figures F-1 and F-2). Traverses 20 km upwind of Baltimore and at distances of 20, 40, 60 and 80 km downwind of the city provided information concerning ozone buildup northeast of the Baltimore-Washington, DC urban areas.

WSU flight #1 (0839-1158) - Ozone concentrations upwind of Baltimore were in the 40 to 60 ppb range at ~1200'. A vertical sounding performed southwest of Baltimore at about 0900 showed an elevated band of O_3 between 1500-2000' with maximum concentrations up to 80 ppb. Between 2500 and 6000' there was a gradual increase in ozone concentration from 60 to 75 ppb. Crosswind traverses 20 km downwind of Baltimore revealed ozone levels of 60 to 80 ppb at 6000', 60 ppb at 4500', and 40 to 60 ppb at 1000'. Passes perpendicular to the southwesterly wind flow 90 km from Baltimore showed no clear cut evidence of ozone plumes. Ozone levels at 1000' and 2500' along the 90 km transect were similar, varying between 70 and 90 ppb. On the return flight leg from near Wilmington to Baltimore, ozone concentrations jumped from 80 ppb to about 110 ppb over Havre De Grace and then increased slowly to about 120 over the eastern fringe of Baltimore.

BNL flight #1 (1407-1739) - The BNL flight route consisted of a crosswind traverse 20 km upwind of Baltimore and several passes across the Baltimore-

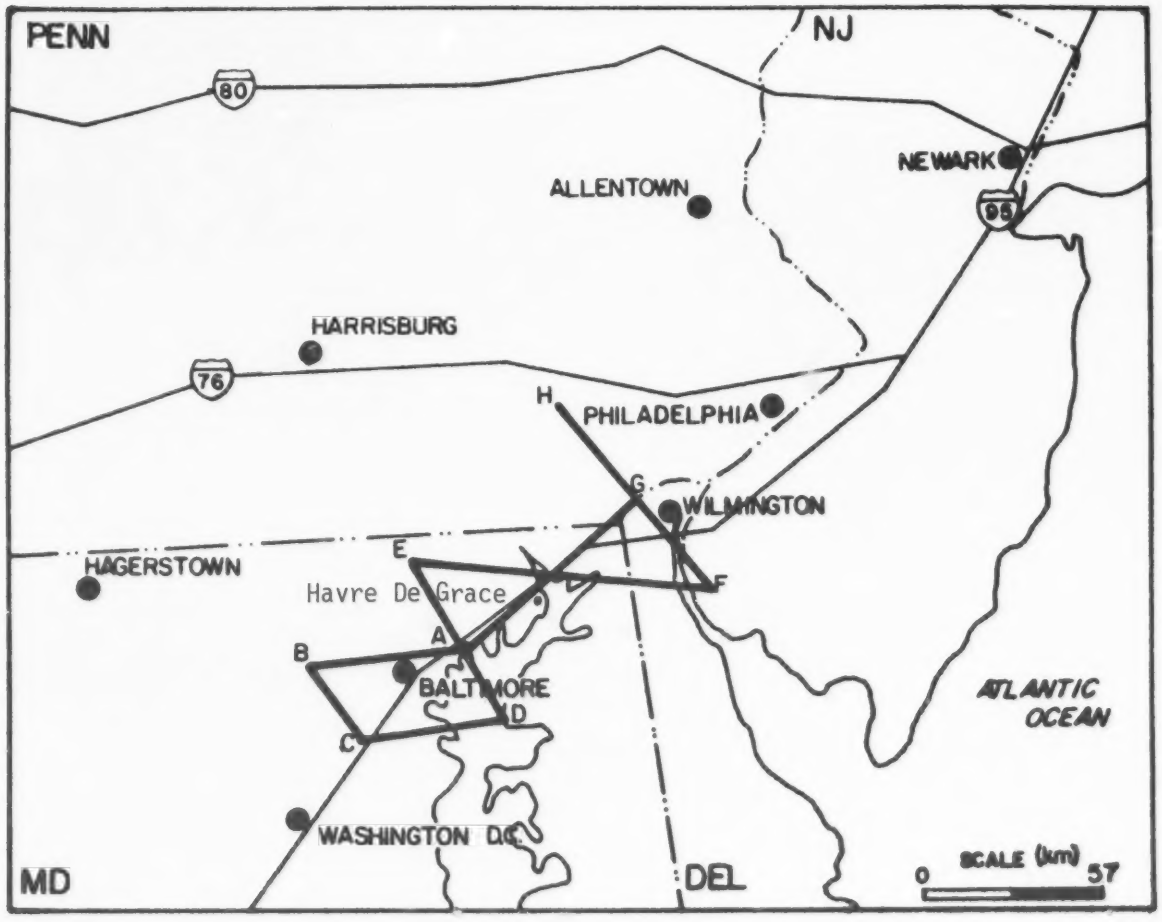

Figure F-1. August 5 morning flight path.

WSU #1

Leg	Altitude	Time
A-B	1500	0839-0857
B-C	1000	0858-0906
C-D	6000	0916-0926
D-A	6000	0926-0932
A-E	1000	0944-0952
E-D	2500	0953-1006
D-E	4500	1007-1021
E-F	1000	1022-1046
F-H	1500	1046-1108
H-F	2500	1109-1127

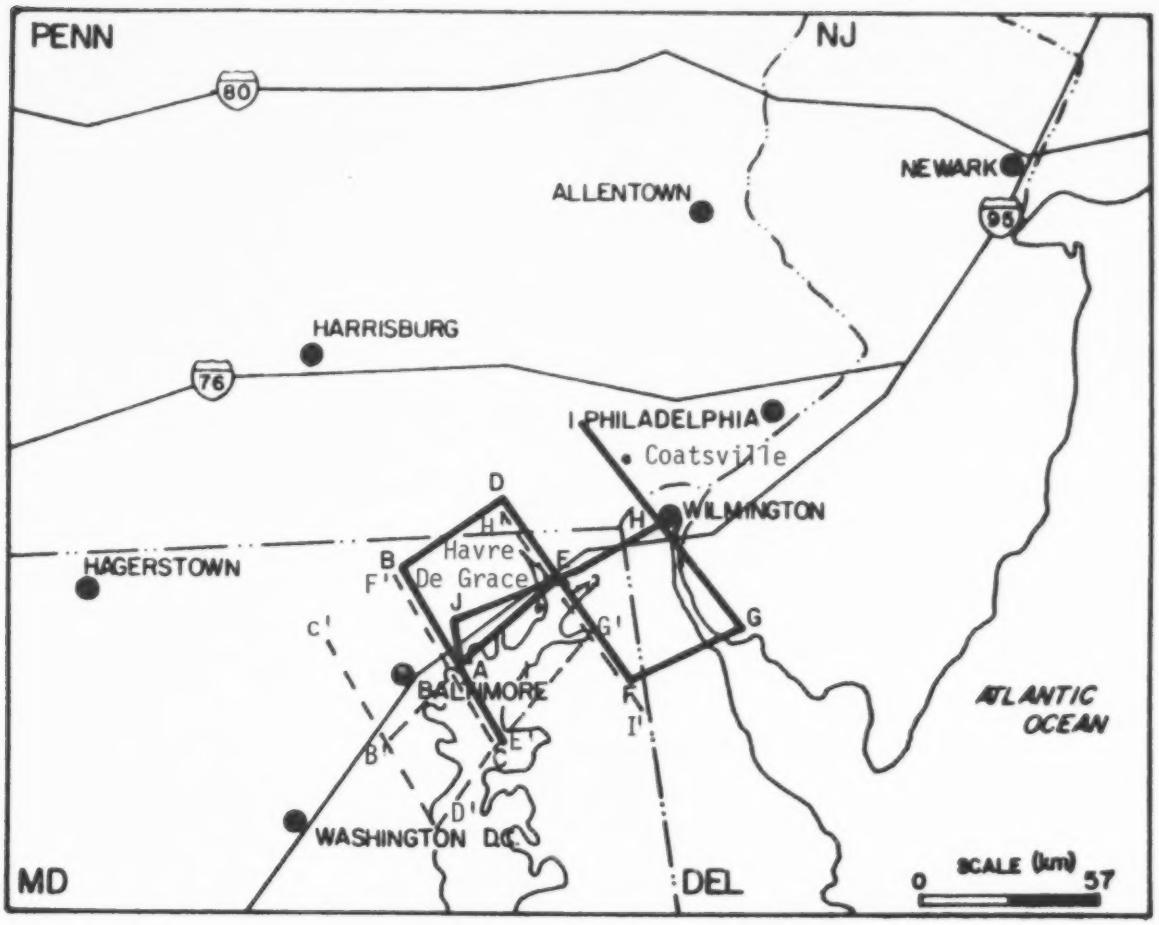

Figure F-2. August 5 afternoon flight paths.

BNL #1 (dashed line)			WSU #2 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B'	1500	1422-1434	A-B	1500	1508-1519
B'-C'	4000	1453-1501	B-C	2500	1520-1540
C'-D'	2500	1503-1518	C-B	4500	1541-1559
E'-F'	1500	1531-1549	D-F	1500	1613-1632
F'-E'	2500	1552-1613	F-D	3000	1633-1653
G'-H'	1500	1625-1638	D-F	4000	1654-1717
H'-I'	2500	1640-1704	G-I	1500	1727-1749
I'-G'	4500	1707-1715	I-G	2500	1750-1814
			G-H	4500	1815-1827
			H-A	2000	1828-1855

Washington, DC plumes at distances of 20 and 60 km downwind. An upwind spiral near the beginning of the flight showed ozone concentrations in the 120 to 140 ppb range up to 4000'. Ozone levels decreased rapidly above that altitude with values in the 60 ppb range recorded above 5000'. As can be seen in Figure F-3, high ozone levels were transported into the Baltimore area during the afternoon hours on August 5. A well defined ozone plume with a peak concentration of about 140 ppb was observed along the crosswind traverse 20 km upwind of Baltimore. A similar ozone pattern was observed during the traverse 20 km downwind of Baltimore. The peak ozone concentration recorded at this distance was 153 ppb. Further downwind at the 60 km distance, peak in plume ozone levels approached 170 ppb.

WSU flight #2 (1508-1855) - The WSU aircraft traversed the region downwind of Washington, DC and Baltimore at distances of 20, 60 and 90 km. At each of these distances, cross plume transects were flown at two different altitudes. Ozone concentrations in excess of 200 ppb were recorded at 2500' on the 20 km downwind traverse. Figure F-4 shows the ozone pattern observed on this cross plume leg. The northern edge of the ozone plume was marked by a very rapid concentration increase from background levels of 80-90 ppb to plume concentrations in the range of 190 ppb. After reaching a peak concentration of about 220 ppb northeast of Baltimore, ozone concentrations gradually decreased to approximately 150 ppb southeast of Baltimore and returned to background levels near the eastern shore of Chesapeake Bay. A similar pattern was recorded at 4500' although concentrations at corresponding points along the traverse were about 50 ppb lower. The peak in plume concentration at 4500' was 155 ppb. At 60 km downwind of Baltimore, highest O_3 concentrations were observed in the immediate vicinity of Havre De Grace. As can be seen in Figure F-5, the peak ozone concentration was about 220 ppb

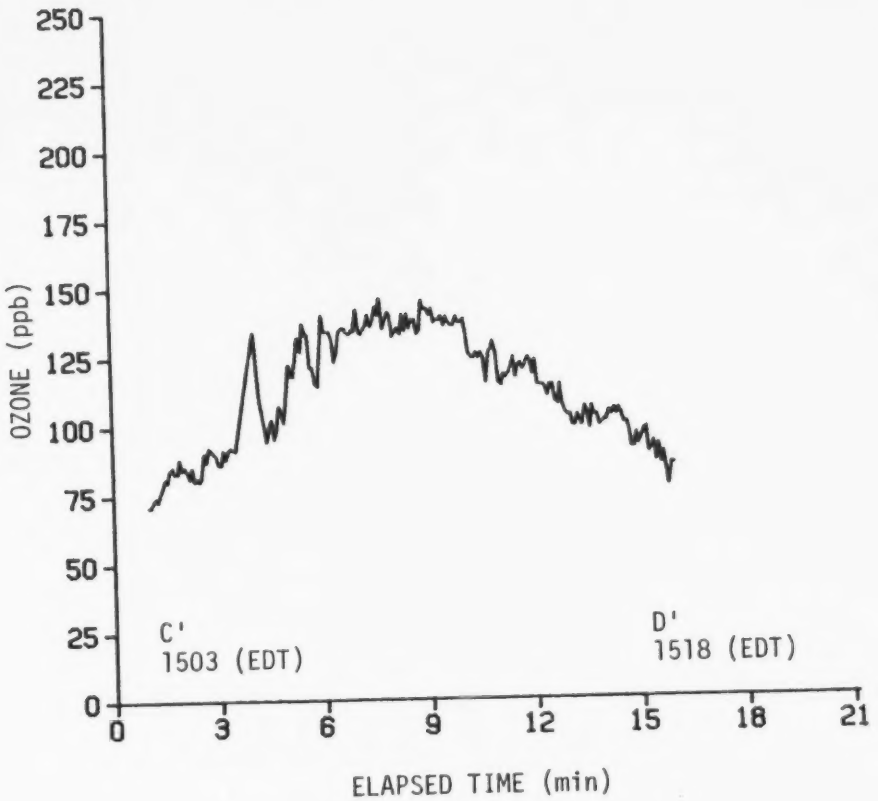

Figure F-3. Ozone profile recorded 20 km upwind of Baltimore at 2500 ft on August 5, 1980 by BNL aircraft.

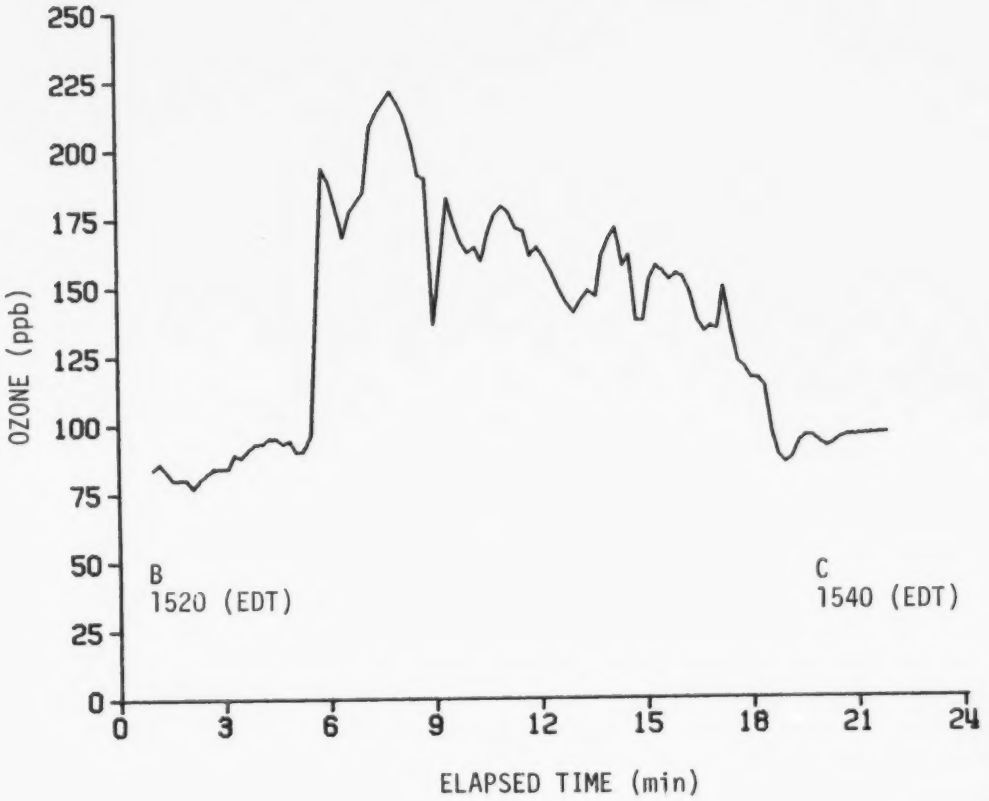

Figure F-4. Crossplume ozone profile recorded 20 km downwind of Baltimore at 2500 ft on August 5, 1980 by WSU aircraft.

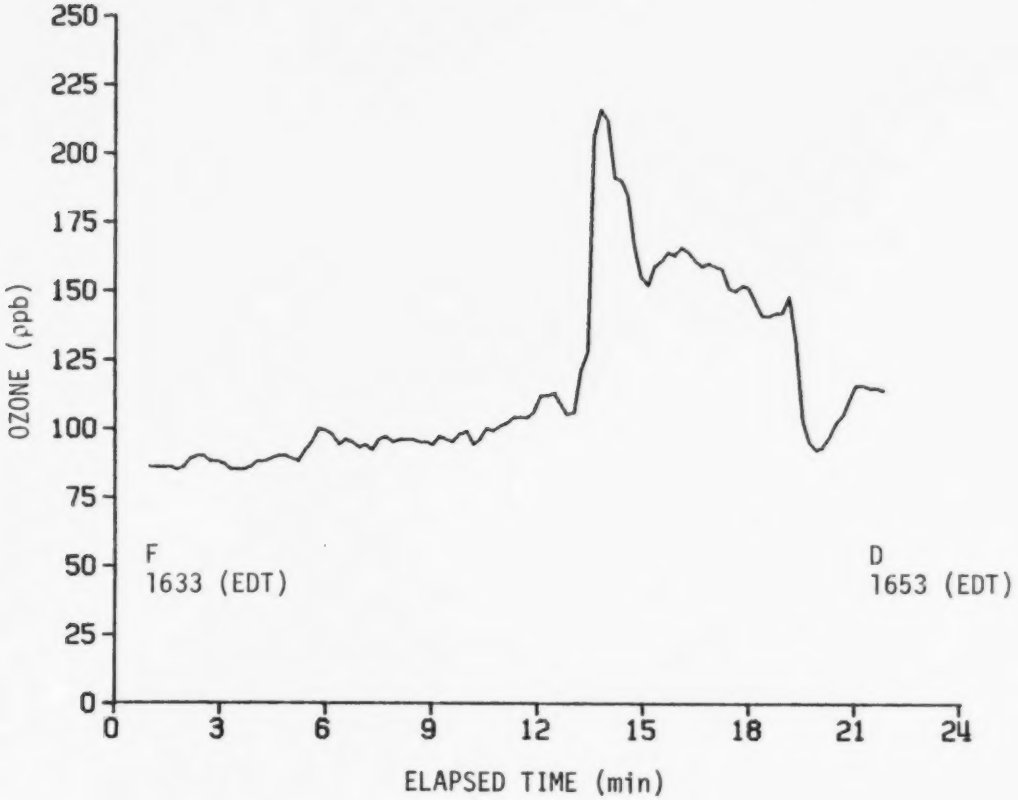

Figure F-5. Crossplume ozone profile recorded 60 km downwind of Baltimore at 3000 ft on August 5, 1980 by WSU aircraft.

at 3000'. Most of elevated ozone plume extended to the northwest of Havre De Grace. A cross plume traverse at 1500' provided an ozone profile nearly identical to that recorded at 3000'. A broad ozone plume with peak concentrations of 150 ppb was observed 90 km downwind of Baltimore. The region of elevated ozone extended in the northwesterly direction from Wilmington, DE to beyond Coatsville, PA.

APPENDIX G

Data Summary and Analysis

August 14, 1980

Weather in the Baltimore-Washington, DC area on August 14 was influenced by a flat high pressure system centered over the region. Scattered to broken cirrus clouds were present throughout the afternoon period. It was a hot and humid day with the maximum temperature reaching 95°F. Winds were from the southwest quadrant throughout the day. A tetroon was released at 1045 from Martin State Airport. It traveled in a northeasterly direction at speeds varying between 20 and 70 km/hr. The tetroon drifted downwind at altitudes between 2000' and 4000'. Aircraft flight legs crossed the tetroon trajectory at distances of 20, 70 and 190 km downwind of Baltimore.

Three aircraft sampling missions were flown downwind of Baltimore between the hours of 0953 and 2019 on August 14. The WSU aircraft surveyed the region from about 20 km upwind to 60 km downwind during the morning hours (Figure G-1). BNL sampled in the region of plume drift out to 90 km during the early afternoon hours and then the WSU aircraft extended the monitoring area to about 190 km downwind of Baltimore during the late afternoon hours (Figure G-2).

WSU flight #1 (0953-1239) - The initial portion of this flight was designed to measure pollutant levels in the region upwind of Baltimore. The aircraft ascended to 1500' and proceeded to a point about 20 km to the northwest of Baltimore. Next, it turned toward the south and flew in a southerly direction to a point about 30 km southwest of Baltimore. A vertical sounding to 9000 ft was performed at this upwind location. Ozone levels at 1500' were in the 60-65 ppb range. Concentrations increased slightly up to 5000' and then began to decrease slowly until the aircraft reached an altitude of 6500'. Above 7000', ozone concentrations were in the 40 ppb range. The upwind leg at 1500' showed evidence of a plume from Washington, DC. The NO_x levels were elevated in the southern portion of the traverse and ozone

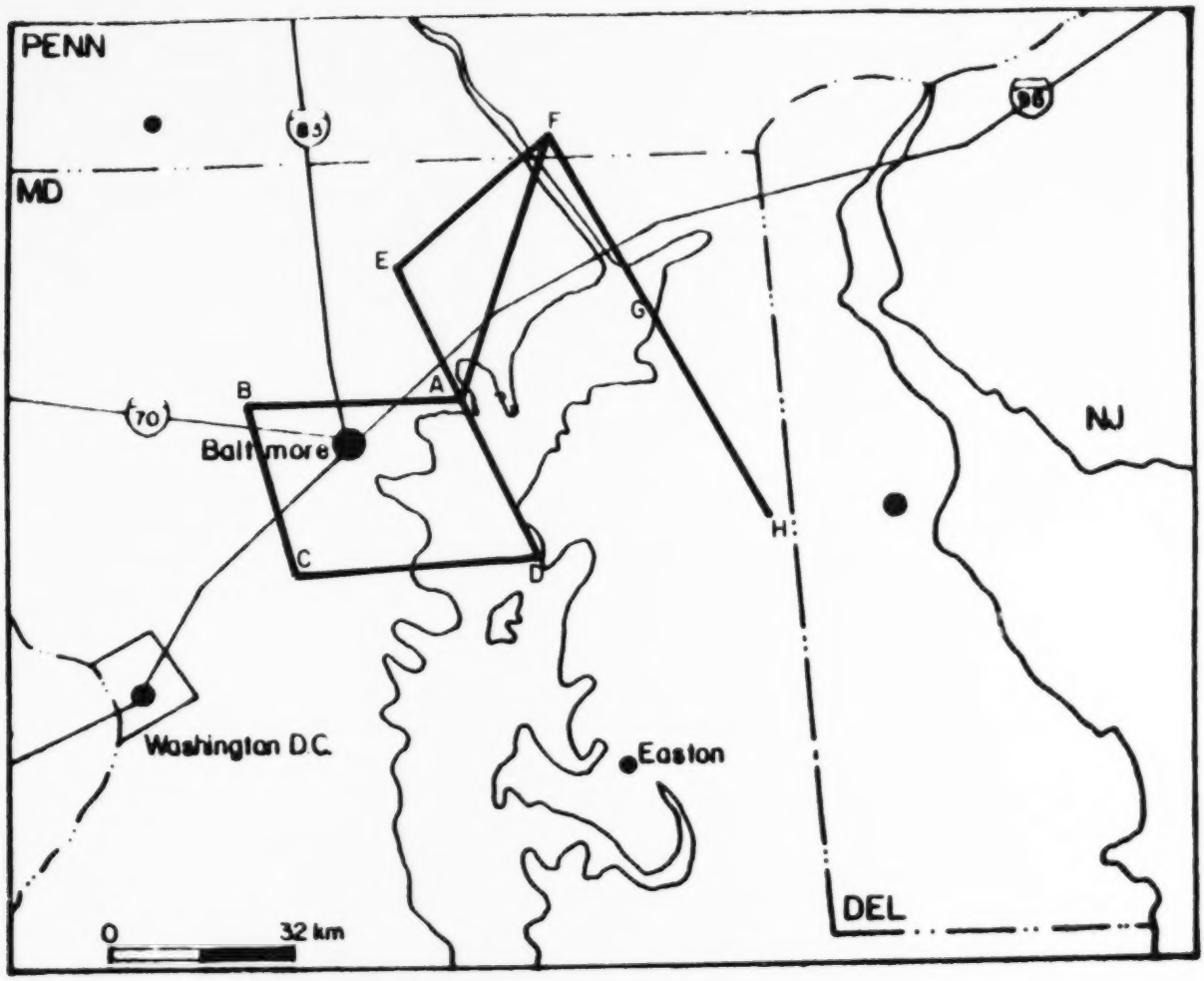

Figure G-1. August 14 morning flight path.

WSU #1

Leg	Altitude	Time
A-B	1500	0953-1007
B-C	1500	1007-1018
D-E	1500	1055-1109
E-D	3000	1110-1124
D-E	4500	1125-1141
F-H	3000	1149-1206
H-F	1500	1207-1224

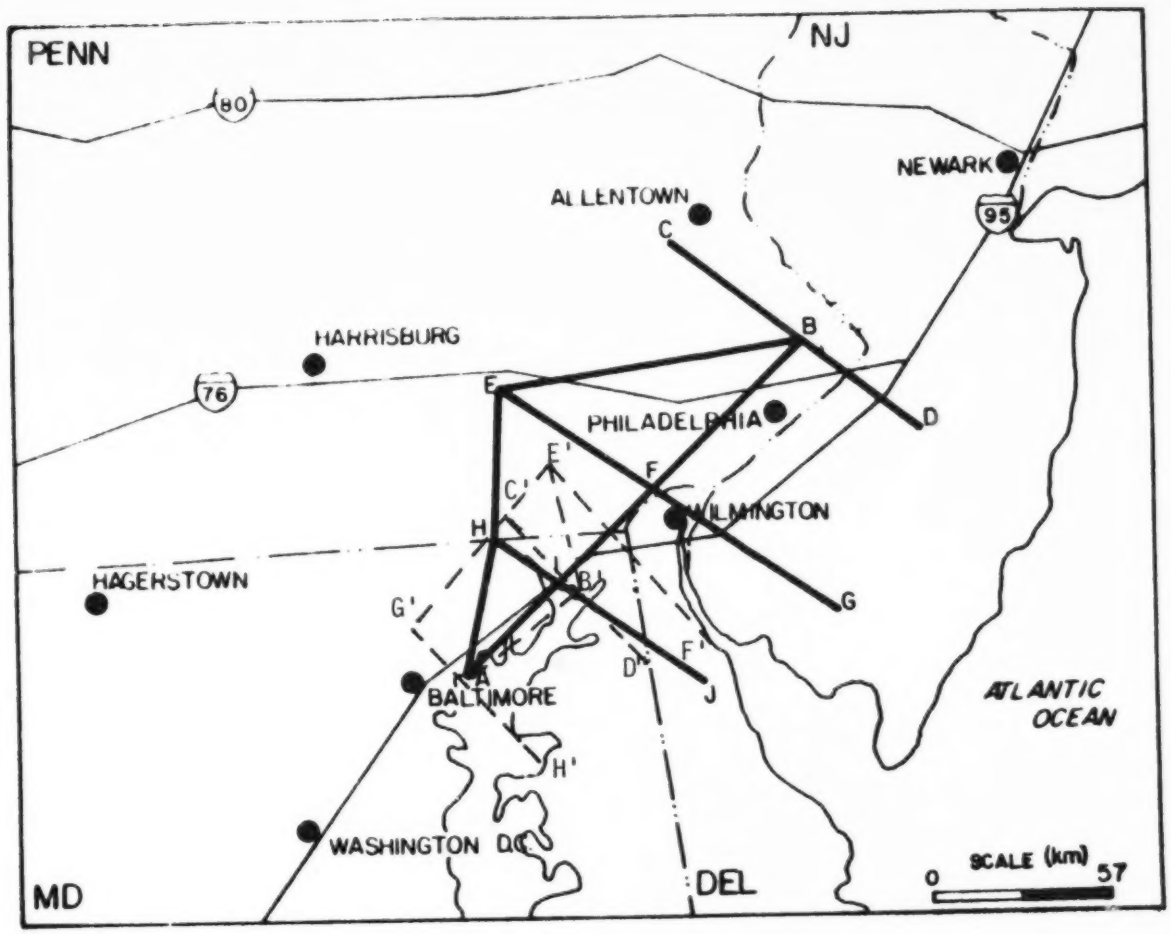

Figure G-2. August 14 afternoon flight paths.

BNL #1 (dashed line)			WSU #2 (solid line)		
Leg	Altitude	Time	Leg	Altitude	Time
A-B'	3000	1223-1236	A-B	1500	1554-1634
B'-C'	2000	1237-1246	B-C	1500	1634-1649
C'-D'	3000	1250-1310	C-D	3000	1650-1713
D'-C'	4500	1314-1333	D-C	4500	1714-1741
C'-B'	6000	1336-1345	C-B	3500	1742-1752
E'-F'	1500	1406-1427	E-G	3000	1817-1846
F'-E'	3000	1430-1448	G-E	1500	1847-1916
G'-H'	3000	1515-1531	H-J	1500	1927-1948
H'-G'	1500	1533-1546	J-H	3000	1949-2005

concentrations were somewhat depressed in this region. Ozone concentrations along the 20 km downwind traverse were in the 70-80 ppb range south of the Baltimore urban area. Directly downwind of Baltimore, NO_x levels increased to about 40 ppb and ozone levels were reduced to about 60 ppb. Ozone concentrations of 60-65 ppb prevailed in the region north of Baltimore. Crosswind traverses along this same 20 km downwind track at altitudes of 3000 and 4500' showed no evidence of an ozone plume or the presence of primary emissions (NO_x). At 1500', ozone levels 60 km downwind of Baltimore were greater than 100 ppb in the area of plume drift. However, a pass along the same 60 km downwind route at 3000' showed little evidence of an ozone plume. In the region directly downwind of Baltimore, ozone levels fluctuated between 60 and 90 ppb which is probably an indication that the mixing level was just below 3000'. Ozone concentrations along the return route to Baltimore at 1500' were generally in the 110-115 ppb range until just before landing at Martin State airport where concentrations greater than 130 ppb were recorded.

BNL flight #1 (1215-1603) - The BNL aircraft made crosswind traverses at distances of 20, 70 and 90 km downwind of Baltimore. The tetroon which had been released during the morning hours was intercepted at about 1235 near the midpoint of the 70 km traverse. Ozone concentrations to the south of the tetroon were about 70 ppb at 3000' while those to the north were generally in the 90 to 100 ppb range. There doesn't appear to be complete mixing to 3000' because ozone concentrations to the north of the tetroon in the region of the urban plume show considerable variation. There were measured concentrations as low as 60 ppb which is about the level recorded in the same vicinity at 4500'. However, there is a clearly discernible ozone plume with maximum concentrations of about 100 ppb at a distance of 70 km downwind of Baltimore. Further downwind at 90 km, maximum ozone concentrations of 110 ppb were

measured at 1500' near the northern end of the crosswind traverse. At this distance, the ozone concentration did not exceed 90 ppb at 3000'. The final portion of this BNL flight consisted of crosswind traverses 20 km downwind of Baltimore. As shown in Figure G-3, a very symmetrical ozone plume was observed at 3000'. Ozone concentrations increased from less than 80 ppb on the fringes of the plume to about 115 ppb in the center of the plume. At 1500', the plume was broader and peak values were not quite as high.

WSU flight #2 (1554-2019) - This flight began with a downwind leg to a point 190 km from Baltimore at which time the aircraft was in close proximity to the tetroon. Crosswind traverses at this distance showed a well defined ozone plume at 3000 and 4500'. As can be seen in Figure G-4, peak ozone concentrations of about 170 ppb were recorded in the central portion of the plume. As was observed earlier in the day when the tetroon was intercepted 70 km from Baltimore, ozone buildup occurred primarily in the region north of the tetroon. However, since much of the region to the south of the tetroon lies in the Philadelphia plume wake, its conceivable that NO emissions from the Philadelphia area depleted ozone levels in the downwind region. Support for this hypothesis is provided by the ozone profile recorded upwind of Philadelphia near Wilmington. Figure G-5 shows the upwind ozone pattern at 3000'. High ozone levels were recorded both to the north and south of Wilmington with reduced concentrations directly over the city. At lower altitudes and in the region between Baltimore and Wilmington, ozone levels were generally below 150 ppb. A traverse 60 km downwind of Baltimore at about 2000 showed ozone levels in the 110-130 ppb at 1500' and slightly higher concentrations at 3000'. An ozone plume was evident in the central region of the 60 km downwind traverse.

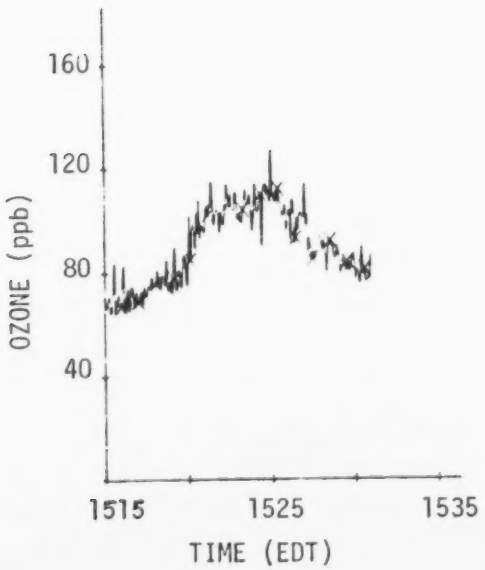

Figure G-3. Crossplume ozone profile recorded 20 km downwind of Baltimore at 3000 ft on August 14, 1980 by BNL aircraft.

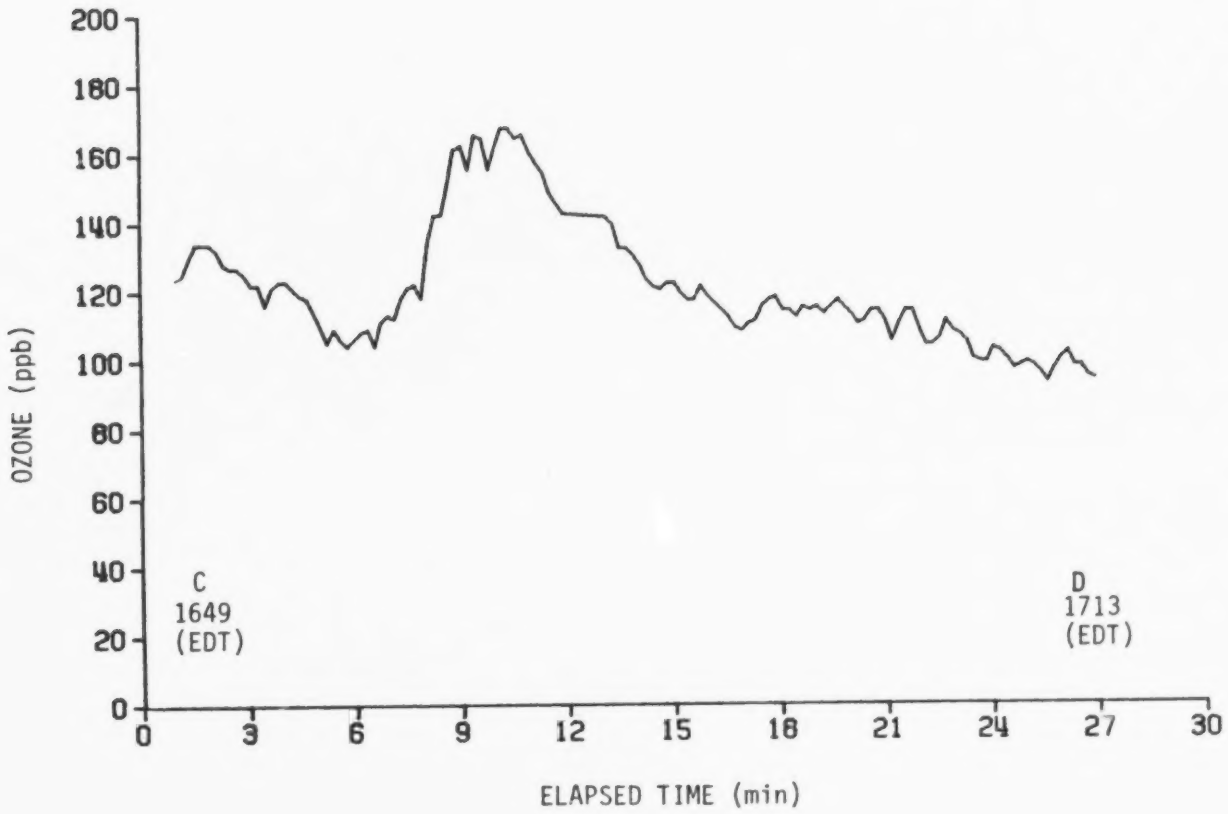

Figure G-4. Crossplume ozone profile recorded 190 km downwind of Baltimore at 3000 ft on August 14, 1980 by WSU aircraft.

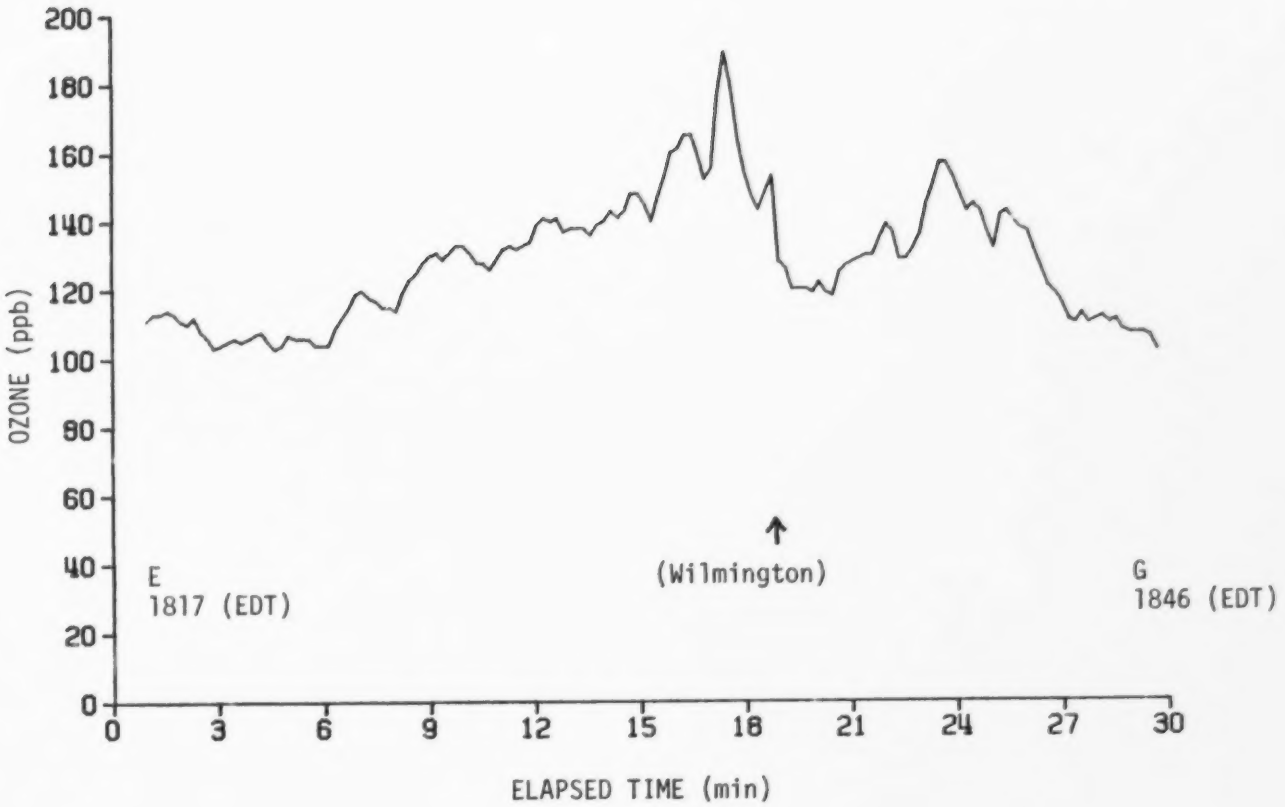

Figure G-5. Crossplume ozone profile recorded near Wilmington at 3000 ft on August 14, 1980 by WSU aircraft.